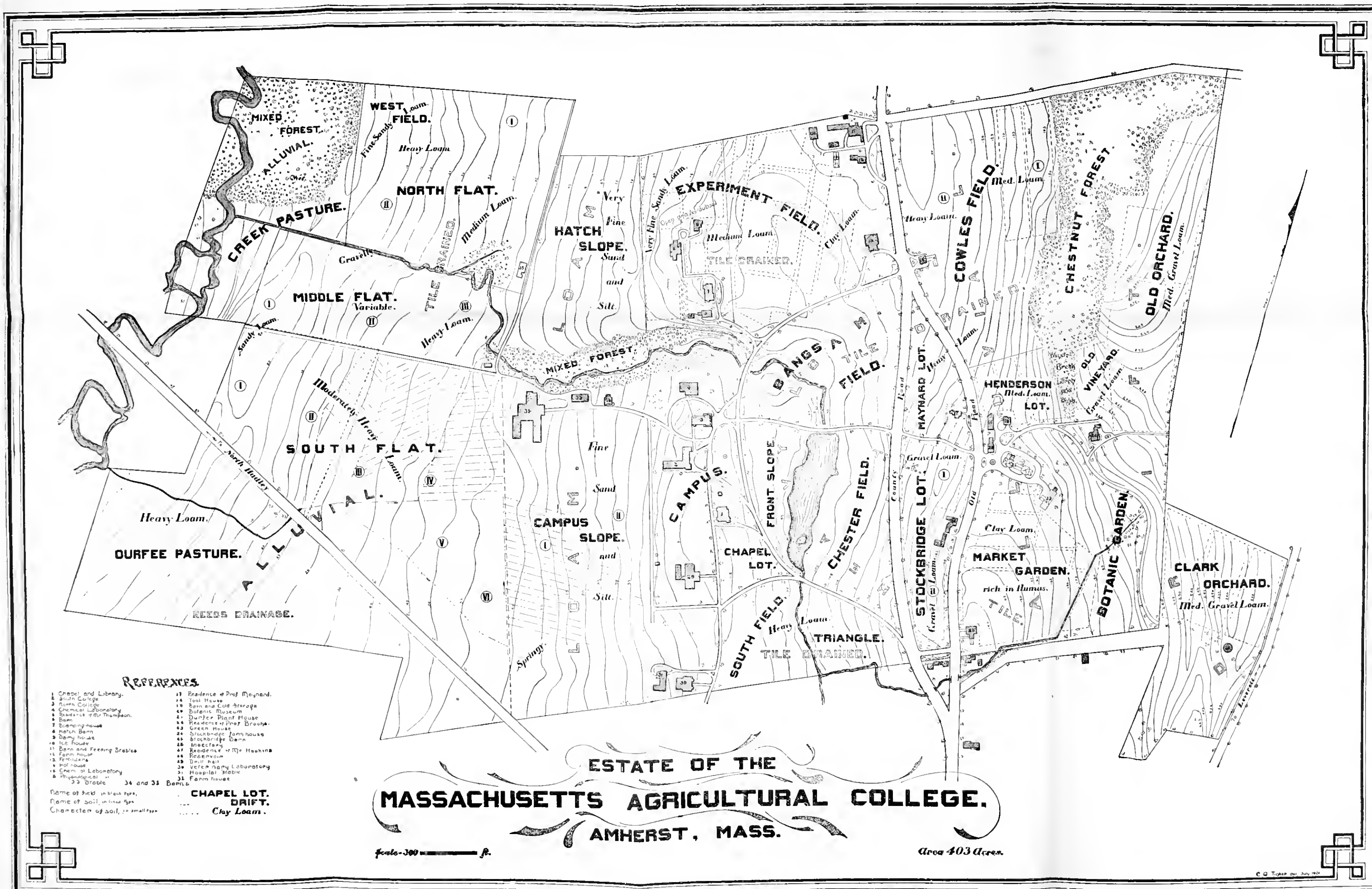
AGRICULTURE

SOILS

AND HOW TO TREAT THEM

WM. P. BROOKS

THE HOME CORRESPONDENCE SCHOOL



ESTATE OF THE
MASSACHUSETTS AGRICULTURAL COLLEGE.
AMHERST, MASS.
Scale 300 ft.
Area 403 Acres.
WEST FIELD.
Fine Sandy Loam.
Heavy Loam
NORTH FLAT.
Medium Loam.
MIXED FOREST.
ALLUVIAL.
CREEK PASTURE.
Gravelly
TILE DRAINED.
MIDDLE FLAT.
Variable.
Heavy Loam.
Sandy Loam.
HATCH SLOPE.
Very Fine Sand and Silt.
LOAM
EXPERIMENT FIELD.
Very Fine Sandy Loam.
Medium Loam
Clay Loam.
TILE DRAINED.
MIXED FOREST
BANGS FIELD.
TILE
SOUTH FLAT.
Moderately Heavy Loam.
ALLUVIAL.
North Hadley
Heavy Loam.
DURFEE PASTURE.
NEEDS DRAINAGE.
CAMPUS SLOPE.
Fine Sand and Silt.
Springs
CAMPUS.
FRONT SLOPE
CHAPEL LOT.
CHESTER FIELD.
SOUTH FIELD.
Heavy Loam.
TRIANGLE.
TILE DRAINED.
County Road
MAYNARD LOT.
Heavy Loam.
STOCKBRIDGE LOT.
Gravel Loam.
Old Road
COWLES FIELD.
Heavy Loam.
Med. Loam.
DRAINED
CHESTNUT FOREST.
OLD ORCHARD.
Med. Gravel Loam.
HENDERSON LOT.
Med. Loam.
OLD VINEYARD.
Gravel Loam.
Clay Loam.
MARKET GARDEN.
rich in Humus.
TILE
BOTANIC GARDEN.
CLARK ORCHARD.
Med. Gravel Loam.
To Leverett
REFERENCES.
1 Chapel and Library.
2 South College
3 North College
4 Chemical Laboratory
5 Residence of Mr Thompson.
6 Barn
7 Boarding house
8 Hatch Barn
9 Dairy house
10 Ice house
11 Barn and Feeding Stables
12 Farm house
13 Fertilizers
14 Hot house
15 Chem. of Laboratory
16 Physiological "
17 Residence of Prof Maynard.
18 Tool House
19 Barn and Cold Storage
20 Botanic Museum
21 Durfee Plant House
22 Residence of Prof Brooks.
23 Green House
24 Stockbridge farm house
25 Stockbridge Barn
26 Insectary
27 Residence of Mr Haskins
28 Reservoir
29 Drill hall
30 Veterinary Laboratory
31 Hospital Stable
32 Farm house
33 Stable 34 and 35 Barns
Name of field, in black type. CHAPEL LOT.
Name of soil, in lined type DRIFT.
Character of soil, in small type Clay Loam.

Agriculture

VOL. I

SOILS, FORMATION
PHYSICAL AND CHEMICAL
CHARACTERISTICS AND
METHODS OF IMPROVEMENT *Including* TILLAGE
DRAINAGE & IRRIGATION

. . *By* . .

WILLIAM P. BROOKS, Ph. D.

The HOME CORRESPONDENCE SCHOOL
THE KING-RICHARDSON CO., *Proprietors*
SPRINGFIELD, MASSACHUSETTS
1901

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ILLUSTRATIONS

Preface

That much may be accomplished by the faithful student through home study is too well known to need argument or proof. The splendid success of the Chautauqua courses, so favorably and so widely known, has abundantly demonstrated this fact; and has shown moreover that the proportion of those undertaking home study who persevere and make substantial gains in mental and will power, in culture, and in practical knowledge is surprisingly large, in view of the many distractions incident to such work. Such being the facts, it is but natural that Chautâuqua should have imitators; hence the origin of correspondence schools is easily explained. These schools are undertaken as business ventures; and it might be thought that the interest of the management in the student would cease with his enrollment and the payment of the required fee. Such a view is superficial and not warranted by the facts, in so far as relates to the best of these schools. Their managers have perceived what any clear-minded person will at once see must be the case, that, as in all business matters, the advantage must be mutual if the institution is to have healthy growth and permanent success. Hence we find the management of correspondence schools intelligently and energetically directed with a view to stimulating and maintaining the enrolled student's interest and leading him on to the completion of the course which has been undertaken.

Courses in business were among the first to be offered by corre-

spondence schools. Their success led to the offering of numerous other courses which also have been successful. At first these courses were pushed mainly in the cities and villages; but now the country districts also are being looked over for students, and, naturally the idea suggests itself—"Why not offer courses calculated to stimulate interest in farming pursuits rather than exclusively such as tempt away from the farm into ranks already crowded?" It is recognized that national prosperity depends most largely upon agricultural prosperity, and that this may be increased by the exercise of greater intelligence. Books cannot make good farmers; but they can help an intelligent student to be a better farmer.

Most sincerely believing, then, in the possibility of the usefulness of correspondence courses in Agriculture, the author has undertaken the preparation of this series of books. It is hoped that they may prove helpful in giving an insight into the scientific principles which underlie the various operations of the farm, and be sources of practical information permanently valuable for reference.

Volume I. treats of the composition and food of plants and tells from what sources the necessary elements are derived. This serves as an introduction to the study of soils, which embraces a brief consideration of the action of the various agencies which have helped to form and to improve them. Especial attention is paid to the action of agencies which are now active; and the means which the farmer may take to promote such action are carefully pointed out. The peculiarities of the different classes of soil and their suitability to different crops are discussed. Then follows a careful study of soils in their relation to air, water, and heat. The chemistry of soils, with especial reference to composition and the more important chemical changes which go on in them, is treated at length. Following this the various operations which have for their object the amelioration of the soil are fully treated. This section includes a careful ex-

planation of the objects, results, and methods of tillage and a description of the principal tillage implements.

Drainage is treated at considerable length, as also is irrigation. Illustrations, many of which have been prepared especially for this work, have been largely introduced and will be found helpful to an accurate understanding of the various subjects.

Throughout the book an effort has been made to present the truths of science in simple language, devoid of technical terms which are not generally understood. This plan has perhaps forced some sacrifice in possible brevity and conciseness of expression; but it is hoped this will make the book more widely useful to the class for which it is intended.

The author has drawn from the most varied sources for assistance in the preparation of this book. Credit in all important matters has, it is believed, been given in the text and no attempt will here be made to enumerate the different books which have been consulted.

Wm. P. Brooks

Massachusetts Agricultural College,
AMHERST, Mass., May 6, 1901.

AGRICULTURE

VOL. I

SOILS AND HOW TO TREAT THEM

I — WHAT AGRICULTURE IS.

1. Agriculture is the art which has for its object the production of plants and animals, or of vegetable or animal products. It closely touches almost every science. It can be most intelligently and successfully carried on only by those who have some understanding of the sciences most nearly related to it: such, for example, as geology, which treats of the earth; chemistry, the science which deals with the composition and properties of things botany, which treats of plants; physics, the science which treats of gravity, heat, light, and other forms of energy; and others which might be mentioned. Agriculture is not in itself a science. It should, however, be scientifically carried on; in other words, it should be carried on in the full light of all the help that science or "truth" pertaining to the things with which it deals can give it.

2. From another point of view agriculture must be looked upon as a business. Success from a financial standpoint will depend largely upon the energetic application, to the art of agriculture carried on in the light of science, of sound business principles. This book and the other volumes of this series are designed to help along all these lines.

II — ESSENTIAL DEFINITIONS.

3. Matter may be defined as anything which has weight and occupies a certain amount of space. Water, salt, sand, air, the growing plant, are examples. The forms of matter are countless.

4. An element is a form of matter which cannot be divided by chemical means into two or more simpler forms. Examples are oxygen, sulfur, gold. The number of elements now known to exist on our globe is sixty-nine.

5. A compound is a form of matter made up by the chemical union of two or more elements. A compound formed by such union is often wholly different in its properties from either of the elements uniting to form it. Water, for example, is a compound. It is formed by the chemical union of two colorless gases, hydrogen and oxygen. Common salt is another compound. This is formed by the chemical union of a gas (chlorin) and a combustible solid (sodium). Every chemical compound is invariable in its composition. It should be remembered that a mere mixture of elements which do not chemically unite with each other does not make a compound. The air, for example, is a mixture of gases, chief among which are nitrogen, oxygen, and carbonic acid gas; but the air is not a compound. It is not invariable in its composition. The proportion of carbonic acid gas, for example, varies as is well known. The air is a simple mixture of gases. The number of possible compounds is enormous.

III — CLASSES OF COMPOUNDS.

6. All classes of matter and all compounds may be put into two classes: organic and inorganic. Organic compounds are derived from plants or animals. Organic matter is matter which has been a part of a plant or animal, and which still retains traces of its original structure. Starch and sugar are good examples of organic compounds. Straw and peat are examples of organic matter. Inorganic compounds and inorganic substances are all those not produced by plants or animals. All mineral sub-

stances are included in this class. Such compounds are found all about us. Examples are common salt, potash, and particles of sand.

7. Comparatively few of the elements known to exist in the world are of direct importance in agriculture. We can consider as of such importance only those elements which are essential parts of soils and plants. These elements are as follows: silicon, aluminum, chlorin, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, potassium, calcium, magnesium, sodium, and iron.

8. Acids are compounds which have sharp burning qualities. All contain hydrogen. Examples are carbonic acid, acetic acid (found in vinegar), nitric acid, phosphoric acid.

9. Bases are compounds which are capable of uniting with acids and taking away their sharp burning quality. Examples are lime, potash, soda.

10. A salt is a compound formed when the hydrogen in an acid is replaced either entirely or in part by a base. In common language a salt may be said to be a compound formed by the union of an acid and a base. Examples are common salt, formed by the union of hydrochloric acid and sodium; nitrate of soda, formed by the union of nitric acid and soda; phosphate of lime, formed by the union of phosphoric acid and lime.

11. Plant food may be defined as any element or compound which, being taken into the plant, either becomes an essential part of the plant or helps the plant to carry on any of its necessary functions. The food of most plants consists of inorganic elements and compounds, and the work of the vegetable world may be said to consist in building from simple inorganic elements or compounds more complex organic substances. The energy or force which is potent in doing this work comes from the sun in the shape of light and heat.

12. *Assimilation* — An element or compound which serves as plant food is assimilated when it or any one of its elements is made a part of the plant.

IV — WHAT THE PLANT CONTAINS.

13. *Importance of knowledge as to this point* — The first object in agriculture is the production of plants, for plants or parts of plants are the food

of our domestic animals. It is of the first importance, then, to know what plants contain and where it comes from.

14. The greater part of the plant is water. If we take a growing plant of any kind, let us say one hundred pounds of green grass, and spread it out in the sunshine or in a dry, airy room, it soon loses a considerable share of its weight. This loss is due to the evaporation of water from the tissues of the plant. Our one hundred pounds of green grass, on becoming thoroughly air dry, will weigh perhaps twenty-five pounds, or possibly less. If, now, we should heat this dry grass in an oven at a temperature not exceeding the boiling point of water (212°) we should find that it loses still further weight. This loss also must be due to the evaporation of water. When the heating has been continued at the same moderate temperature until there is no further loss, it will be found that we have perhaps only fifteen or twenty pounds of material remaining. The difference between this weight and the original one hundred pounds represents the water which was contained in the growing plant. In other words, the proportion of water in grass may vary from about eighty to eighty-five per cent. The grass plant, however, is no more watery than many other plants. The proportion of water in plants varies for the different kinds and with plants of different degrees of ripeness; but all plants when in full vigor of their growth will be found as a rule to contain from about seventy-five up to ninety per cent. of water.

15. *The organic part of plants* — If we should take the ten or twelve pounds of thoroughly dry grass obtained from the one hundred pounds of green grass and burn it, we should have left only a very small amount of material — the ashes. What has disappeared is the organic substance of the plant; and this, it must be evident, makes up almost all of what is left after the water has disappeared. The ash of most plants will be found to amount to only one to three per cent. of the entire plant.

16. *The ash of plants* — As has been stated in the above paragraph, the total amount of ash in the growing plant constitutes but a small portion of the whole, usually ranging between one and three per cent.; but although the proportion is small, the constituents of the ash are none the

less necessary to the plant than are those constituents which are present in large amounts.

17. *Summary* — Plants then contain water ; organic substances, such as cell walls and wood (making up the framework of the plant), starch, sugar, fat, etc. ; and ash, composed of inorganic or mineral elements. The elements found in water are hydrogen and oxygen. The elements contained in the organic portion of the plant are carbon, hydrogen, oxygen, and nitrogen. The inorganic elements, nearly all of which will be found in the ash, are phosphorus, sulfur, potassium, calcium, iron, sodium, chlorin, and silicon.

18. *The necessary elements* — It has been proved by experiment that plants can grow equally as well without as with the sodium and silicon, and, according to some authorities, chlorin also. These elements, then, cannot be regarded as necessary elements of plant food. All the others named are necessary. If the attempt be made to cause a plant to grow in the absence of any one of them, it is always unsuccessful.

V — THE NATURE OF THE ELEMENTS USEFUL TO PLANTS AND THE SOURCES FROM WHICH PLANTS DERIVE THEM.

19. *Hydrogen* — This element is a gas which will burn freely in air. When it burns it unites with oxygen and forms water. Water, in one sense then, is the ash produced by burning hydrogen gas. This element is useful to plants only when combined with oxygen in the form of water. The water which plants need they take in through their roots. It has been thought by some that plants are able to take in water through their leaves, but this is not now believed to be the case. The amount of water consumed by the growing plant is enormous. It has been pointed out that the proportion of water in the growing plant often amounts to eighty-five or more per cent. of the entire plant. The amount of water, however, found in the plant at any one time constitutes but a very small proportion of the water that the plant uses during the period of its growth. It has been found by experiments with growing plants that in many cases the total amount of water used by the crop is equal to four or five hundred times the

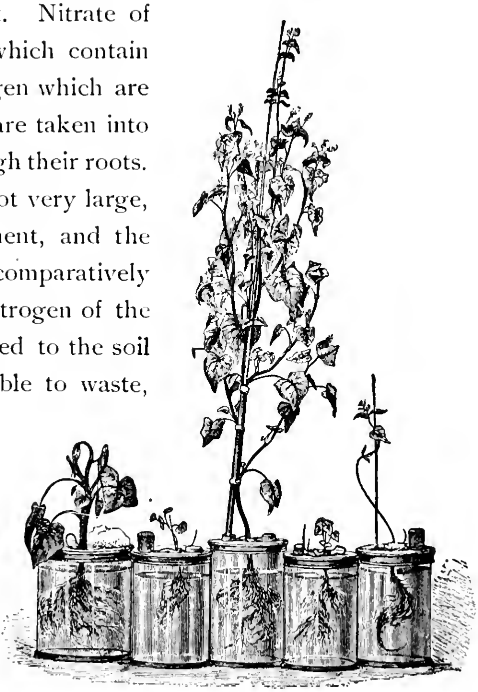
total weight of the dried crop. Throughout the period of their growth plants are taking in water through their roots and throwing it off through their leaves. The value of soils depends in very marked degree upon their ability to furnish water to the growing crop.

20. *Oxygen* — This element in uncombined form is a gas. It comprises, as is generally known, about one-fifth of the open air. This oxygen gas is useful to plants in the same way that it is useful to animals and man. Plants, in one sense of the word, breathe as truly as do animals or men, and respiration in plants as with animals and man is supported by the oxygen of the air. Oxygen is a constituent also of almost every compound that plants use as food, *e. g.*, water, carbonic acid gas, and nitric acid. The natural supply of this element, however, whether in free or combined form, is adequate for the needs of plants, and the farmer has not to consider oxygen as a manurial element.

21. *Carbon* — The element carbon is a solid. An example of a substance which is nearly pure carbon is charcoal. In the form of a solid like charcoal carbon is of no direct use to plants. The compound of carbon upon which vegetation depends is carbonic acid, *i. e.*, 1 carbon combined with 2 oxygen. This compound is found in the air, of which it usually comprises about one twenty-five hundredth part. The leaves of plants are so constructed that the air finds its way into them, and when the plant is exposed to light the carbonic acid of the air is assimilated. Although the carbonic acid of the air comprises but a small part of the whole, plants are able to obtain from the air all of this element which they need. So far as feeding the plant is concerned, then, the presence of carbon in the soil is unnecessary ; but this element is a constituent of the organic or decaying vegetable matter of the soil, and the presence of such matter is essential to fertility. Carbon constitutes a large share of all bulky manures.

22. *Nitrogen* — Nitrogen is a gas. It comprises about four-fifths of the open air. Nitrogen in this form becomes useful to plants of the clover family through the assistance of plants of microscopic dimensions with which the clovers may be said to enter into partnership. None of the other common plants of the field, garden, or orchard are able to make use of the

free nitrogen of the atmosphere. They must all find access to some compound of this element in the soil ; and the most useful of the nitrogen compounds to the plant are ammonia and nitric acid. The latter compound appears to suit plants best, but it cannot be taken up by the plant until it is combined with a base to form a salt. Nitrate of soda is the best known of the salts which contain nitrogen. The compounds of nitrogen which are used by all ordinary plants as food are taken into the plant, after being dissolved, through their roots. The amount of nitrogen in plants is not very large, but it is an absolutely essential element, and the supply of it present in most soils is comparatively small. Moreover, both the stored nitrogen of the soil and nitrogen which may be applied to the soil in manures or fertilizers are very liable to waste, being washed out of the soil with the water which soaks through it. As a consequence this element is often deficient in soils. It is, therefore, one of the most important elements of manures and fertilizers, and one which farmers must usually supply for all crops except those of the clover family.



4 3 1 2 5

FIG. 1. BUCKWHEAT: 1, supplied with all elements necessary to plants; 2, supplied with all except potash; 3, supplied with all except potash, but with soda instead; 4, supplied with all except lime ; 5, supplied with all except nitrogen. The results indicate the absolute necessity of potash, lime, and nitrogen; and that soda cannot take the place of potash.

23. *Phosphorus* — This element is a solid which will burn freely in the air. When it burns it unites with oxygen and phosphoric acid is formed. This acid, combined with a base to form a salt, is the compound of phosphorus, which is directly useful to plants. The salts containing phosphoric acid (phosphates) are dissolved and taken in by the roots. The quantity of phosphoric acid in plants is not very large, but there is comparatively little of this compound in most soils. It has been found by expe-

rience that salts of phosphoric acid, which are known as phosphates, must often be supplied by farmers either in manures or fertilizers in order to make their fields productive.

24. *Sulfur* — The element sulfur is a solid, usually familiar to all. It burns quite freely, and when it burns it unites with oxygen, forming sulfuric acid. It may help to fix the fact in mind that both phosphorus and sulfur burn freely, to remember that both of these elements are used in the tip of the ordinary friction match ; the phosphorus at the very tip, because it ignites most freely, and the sulfur a little back of the tip, because it takes fire readily from the burning phosphorus and thus insures the ignition of the wood. The proportion of sulfur in plants is small, and soils in general contain considerable of this element in the form of sulfuric acid, which, combined with a base to form a salt, is the form in which plants need sulfur. Such salts must be dissolved and taken in through the roots. A good example is sulfate of potash, a well known fertilizer. This fertilizer, however, is not usually employed for its sulfuric acid, but for its potash; and, indeed, it appears to be practically seldom if ever necessary to supply sulfuric acid ; for, although the original store in the soil would doubtless in time become exhausted, nature has methods whereby the supply is kept up. As a matter of fact, moreover, sulfur is found in all manures and in many fertilizers. This element, therefore, has not to be especially provided for by the farmer.

25. *Potassium* — This element is a solid which can easily be burned, and as it burns it unites with oxygen forming a compound — potash. Potash is composed of 2 potassium and 1 oxygen. It is this compound which is important in agriculture. Potash, however, has caustic, burning qualities, and cannot be taken up by plants unless combined with an acid to form a soluble salt. The most useful salts are muriate of potash, sulfate of potash, nitrate of potash, and silicate of potash. These must always be taken up by the plant roots. The supply of potash in soils is often insufficient to produce good crops, and it is one of the most important of the constituents of manures and fertilizers.

26. *Calcium* — This element is a solid which can be easily burned. As

it burns it unites with oxygen forming lime. Lime is composed of 1 calcium and 1 oxygen. It is as lime that this element is important in agriculture. As is the case with potash, however, uncombined lime would burn and injure the plant tissues as it burns the skin. Lime, therefore, like potash, must be combined with an acid before plants can take it up. The most useful salts of lime are sulfate of lime (land plaster), phosphate of lime, carbonate of lime, and nitrate of lime. These salts must be dissolved, and taken out of the soil by the roots. The quantity of lime in most plants is large, but lime being found in quite large amounts in practically all soils, it is seldom necessary to apply salts of lime to the soil as a direct source of food for the plant. As will be pointed out under the subject Manures, however, there are many soils to which an application of lime in some form is essential, but this is not in most cases because the plant cannot find as much lime in the soil as it actually needs, but because the lime improves the general condition of the soil.

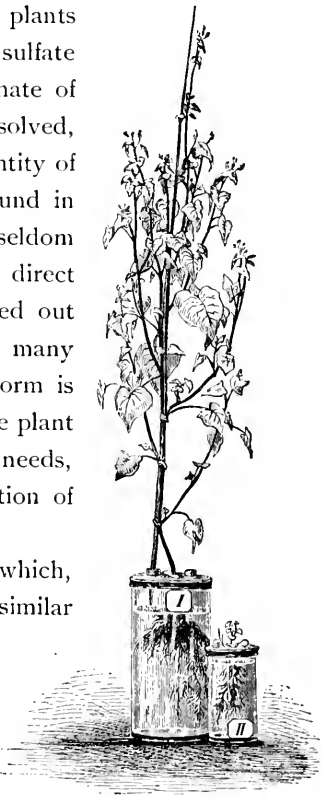


FIG. 2. BUCKWHEAT: *I.* All elements needed have been supplied. *II.* Elements supplied as in *I* with the exception of potash, which has been withheld.

27. *Magnesium* — Magnesium is an element which, in its agricultural relations at least, is entirely similar to calcium. Like calcium it burns, uniting with oxygen to form magnesia. Magnesia is composed of 1 magnesium and 1 oxygen. The plant uses magnesia only in the form of one of its salts. The sulfate of magnesia is the best form, but the plant may also use either the carbonate, the phosphate, or the nitrate. The plant takes salts of magnesia from the soil through the action of its roots. The quantity of magnesia contained in plants is often considerable, but the supply in most soils is so great that the application of fertilizers containing magnesia is seldom necessary.

28. *Iron* — The element iron is a well known solid. Like the other

elements, this one unites with oxygen under suitable conditions, but it will not burn as freely as the other elements we have been considering. When exposed to the action of damp air, or when kept wet and exposed to the action of air, iron slowly combines with oxygen. The compound thus formed is known in everyday language as iron rust. Iron rust is in reality iron oxid, and is composed of 2 iron and 3 oxygen. As is the case with the other elements, so here this compound of oxygen with the element must be further combined with an acid to form a salt before the plant can use it. The most useful of the salts of iron are the phosphate of iron, the sulfate of iron, and the chlorid of iron. These salts must enter the plant in solution through the roots. The quantity of iron required by plants is very small, but unless they can find this small quantity their leaves, instead of becoming green, must always remain pale or white. There is probably invariably sufficient iron in soils so that plants can find all they need.

VI — SUMMARY.

29. *What a plant contains* — We may in brief then say (and in this form the matter should be easily kept in mind), plants must have for healthy growth : free oxygen to breathe, water to drink ; four acids,—carbonic acid, nitric acid, sulfuric acid, and phosphoric acid ; four bases,—potash, lime, magnesia, and iron oxid.

30. *Sources of plant food* — The oxygen is taken from the air ; the water from the soil ; and nature supplies both in sufficient amounts,— water sometimes excepted. The leaves take the carbonic acid needed from the air, where the supply is inexhaustible. The other acids and the bases can be taken only when combined as salts, and the roots must find these salts in the soil. The only substances in our list usually deficient in soils are nitrogen, phosphoric acid, and potash.

VII — ELEMENTS ALWAYS FOUND IN PLANTS BUT NOT KNOWN TO BE NECESSARY.

31. *Chlorin, silicon, and sodium* — Besides the necessary elements which have been considered, plants always contain chlorin, silicon, and

sodium. All of these are taken up by the roots of plants in the form of salts. Chlorin and silicon first form acids, and must combine with some base to form a salt. The salts of chlorin are called chlorids or muriates, the latter being an old name still used in commerce. The salts formed by silica are known as silicates, and these are the most common and most abundant compounds found in soils. Sodium is in all respects much like potassium. It unites with oxygen to form soda, which is 2 parts sodium and 1 oxygen. It unites with acids to form salts. There can never be any necessity to supply these elements as food for plants, for two reasons: first, plants can grow equally well without them; and, second, all are usually abundant in soils.

VIII — A SOIL ELEMENT NOT FOUND IN PLANTS.

32. *Aluminum* — The element aluminum, practically always found in soils and usually in very large amounts, never becomes a part of the plant. Uncombined aluminum is a metal which is now becoming much more common and cheaper than formerly, because men have learned how to manufacture it. In general appearance this material is not unlike silver, but it is much lighter in weight. This material is not found in nature, for aluminum exists naturally only in the form of some of its compounds. The compound of aluminum and oxygen known as alumina is the one of agricultural importance. This is a base, and in soils exists chiefly in combination with silicic acid as silicate of alumina. Clay is made up almost entirely of silicate of alumina, and, as is well known, clay is one of the most important and valuable of the constituents of soils.

IX — THE SOIL.

33. *Soil defined* — Soil is the name given to that portion of the earth at or near the surface, which consists largely of fine particles. It is that part of the earth into which plants send their roots, and from which they take much of their food. The soil furnishes support for the plant, and tempers and stores the heat of the sun as well as supplies food.

34. *Kinds of material found in soils* — All fertile soils contain the two

classes of matter which we have defined, viz.: inorganic matter and organic matter.

35. *Inorganic matter* — The inorganic matter of soils is derived principally from rocks, which are broken up and made more or less fine by the action of the various agencies which are to be presently considered. In most soils inorganic matter makes up by far the larger part. This can be shown by bringing a soil to a red heat over a hot fire. We have seen that if a plant be thus heated, nearly all of it disappears; we have only a small amount of ash or inorganic material remaining. The results with most soils will be very different. The ordinary soil will shrink but little on burning, and this is because it is mainly composed of inorganic materials, for only the inorganic materials remain after burning.

36. *The organic matter of soils* — The organic material found in soils comes from plants or animals. It is either vegetable or animal matter more or less decomposed. In practically all soils the organic matter which is found consists almost exclusively of partially rotted vegetable matter which comes from the roots, stubble, stems or leaves of plants that have been grown there, or from manures which primarily come from the food of animals, which is vegetable matter, so that the real source of organic matter in the soil, even if it is derived from manures, is still vegetable material.

X — FORMATION OF SOILS.

37. *A bit of the history of our globe* — It is believed by those who have studied the matter, that our globe was at one time a part of the sun, when it was intensely hot,— so hot probably that all the forms of matter with which we are acquainted would be melted, or perhaps converted into gases. At this time, and of course for many thousands of years afterwards, there could have been no living thing on our earth. Our earth, however, having been separated from the sun and carried a considerable distance from it, would of course begin to cool. As it cooled, many of the intensely hot gases would become fluid, and, as the cooling went on, this fluid would gradually change to solid and we should have the beginning of rock formation. This rock crust would at first be thin, just as the crust of ice which is

formed upon a pond in winter is thin ; but with the progress of time its thickness would increase, and it would ultimately become so thick that the heat from the interior would be felt but little at the surface. In the course of time the surface would become sufficiently cool so that water could remain upon it, and as soon as this became possible plants would be able to exist. We know that the earliest plants were quite different from the crops of the field as we see them to-day. We know that at this period in the earth's history such forms of life as the common plants and animals of our time would have found it impossible to exist, because conditions were wholly different from the conditions of to-day. We know, however, that conditions as they exist to-day are a natural development from earlier conditions, and it is our purpose to attempt to give an idea of some of the more important of the agencies which have produced from primeval rock the soils as we find them to-day. We know that everything which we find in our soils must have come primarily from the primeval rock and from the air. On burning, elements which come from the air primarily go back to the air. As has been pointed out, we find on burning most soils that there is but little loss. This shows us that most of the material found in soils came in the first instance from rocks. One of the most important steps, then, in soil formation is the pulverization of the rocks. This is the process which has been going on slowly for millions of years, and one which is still going on to-day. At the same time that in some places agencies have been at work changing rocks into soils, other agencies have been at work in other places changing soils into rocks. Our study of soils does not make it necessary that we should consider at any length the action of agencies of the latter class. It is, however, important to recognize that many of the common rocks which we see about us have once been soils. Sandstone is an example. Rocks of this kind are formed by the hardening into stone of sands, as the name indicates. Conglomerates or "pudding" stones furnish another example. These are formed by the hardening of gravels. Under changed conditions such rocks may once more be broken up and become a part of soils. The materials making up the crust of our earth may thus be worked over and over again.

38. *The chief steps in soil formation* — As has been indicated, one of the most important steps in soil formation is the pulverization of the rocks; but there are several other processes involved. One of the most important of these in the case of practically all the soils of New England is the transportation of material. Most of the soils in the northern part of our country are made up of materials which have been brought to their present location by the action of some outside force, and so in studying soil formation we have to consider all those agencies which are capable of moving such materials. Further, the simple grinding or pulverization of rocks will not make a fertile soil howsoever rich in elements of plant food the rock may be, for the elements as they exist in the rock are not in such form that the plant can use them. A crib containing corn on the ear, in one sense of the word contains plenty of food for man, and yet a man allowed to help himself only from this source would probably starve. There is food enough, it is true, in the corn crib, but it is not in such shape that he can use it. So in the rock which has been pulverized there may be food for the plant, but it is not in such shape that the plant can use it. Before the man can use the food found in the crib, the corn must be shelled and ground and the meal made into bread. Before the food in the rock can be used by the plant, the rock must be ground and the rock meal made into bread. As the man calls the cook into his service to prepare bread from the corn meal, so nature works in the service of the plant to prepare plant bread (available plant food) from the material contained in the rock meal. The agencies which nature employs for this purpose are chemical agencies, and the elements upon which they depend are found in the air and in the water. Chemical action, therefore, as well as the agencies which grind and move materials, must be considered in the study of soil formation.

39. *The agencies active in soil formation* — The agencies acting in one or another of the ways which have been indicated, and in some cases in more than one of these ways, are the following: —

Changes in temperature.

Gravity.

Moving water.

Moving ice.
Winds.
Chemical action of air and water.
Action of living plants and animals.
Effects of organic matter.

XI — MECHANICAL AGENCIES.

40. *Changes in temperature* — In the first place we have to point out that as the earth cooled, like all cooling bodies, it grew smaller, and as a result of this decrease in size the original rock crust became too large, and the face of mother earth became wrinkled ; the mountains and mountain chains and the valleys being respectively the summits of these wrinkles and the hollows between. But for the inequality in surface produced in this way there would be no differences in level, and accordingly the entire face of the earth would have been evenly covered with water. The formation of mountains and valleys and sea basins is the direct cause of the movements of water which, as will be pointed out, have played so important a part in forming our soils.

When rocks, especially those which are made up of crystals, such, for example, as granite, are heated and cooled the effect is to weaken their structure or to break them. Sudden or violent and great changes in temperature produce more marked effects than slow or moderate changes. All must have seen the effects of fire on the granite foundation of a building. The more moderate changes which occur in nature, due to the alternate exposure to the sun and the cold, are, however, not without their effects. Rocks are gradually weakened, and in many cases cracked and small pieces split off from them as the result of such exposure. The effect of exposure to cold is not important unless the rock contains water. Practically all the rocks at the surface of the earth, however, contain more or less water. This may fill cracks and fissures which are large enough to be seen, or it may simply be soaked up by the rock. In either case if the water is converted into ice, its expansion may result in breaking the rock. It is well known to many that large rocks are sometimes split by drilling holes in

lines, allowing these to fill with water, the water, upon freezing, splitting the rock. The splitting off of rock fragments, however, from the point of view of soil formation, is less important than the splitting off from the surface of finer particles in the shape of sand or finer earth as a result of the formation of ice in the rock. By this action the rocks and stones of our fields to-day are being slowly broken up; are slowly adding to the quantity of soil. This action even extends to some of the finer particles of the soil itself, causing them to break up into yet smaller fragments.

41. *Gravity* — In obedience to the attraction of gravitation, the particles which go to make up soils have a constant tendency to move from higher to lower levels. At the foot of precipices or steep slopes are often found accumulations of fragments, some of considerable size and some fine, which have tumbled or slid from above to the foot of the slope. Soils formed in this way, however, are of little if any practical importance in most parts of the world. It has been noticed, however, that the soil particles of all slopes appear to have a constant tendency to work down the slope. This tendency is increased when the soil freezes, but goes on in lesser degree at all times. As a consequence of this action the soils on the upper portion of slopes and hillsides have a tendency to become constantly thinner, while those near and at the foot of slopes become deeper and deeper as a result of the addition of material coming down from above.

42. *Moving water* — The action of moving water in soil formation is of three distinct kinds. It wears and grinds, it transports, and it sorts soil materials.

43. *The wearing action of water* — Though water appears to be a soft and yielding substance, it is capable of wearing into solid rock. This action is of course slow, but continued through ages it produces marvelous effects. Instances have been noticed where this steady fall of water in drops, coming drop, drop, drop, hour after hour, day after day, through years and centuries, has worn holes of considerable depth in the solid rock floor of dungeons or caves. It is not, however, until water gathers in considerable volume and moves at a high rate of speed that its action of wearing and grinding the rocks becomes very conspicuous. In practically

all of these cases, however, the wearing and grinding due to the motion of the water are greatly increased by the fact that it moves along with it sand, stones, and even rocks. These must, of course, grind and wear each other and the bed of the stream in which they are found. The most remarkable examples illustrating the wearing effect of moving water are afforded by the cañons of Colorado and some other western states. Here the streams have worn narrow valleys with almost vertical walls into the solid rock, in some instances a half mile or more in depth. Great as is the effect in lowering the bed of the stream, the wearing action upon the rocks and stones moved by the stream is perhaps even more important. These rocks and stones when first torn from the parent ledge must have had angular and jagged outlines and rough surfaces. As we look at such rocks and stones as we find to-day in the beds of rivers and on the seashore, we find them smooth and round. This is because in rolling over and over each other the sharp projections have been worn off. The material thus separated must ultimately become a part of the soil.

44. *Water carries materials* — Moving water is continually carrying soils, and sometimes even stones or rocks, from higher to lower levels, and in this way has played a most important part, and is playing an important part, in soil formation. In time of flood almost all streams gather up and carry forward enormous quantities of soil. The turbid appearance of streams at such times is abundant evidence of this. Many streams are continually carrying enormous quantities of fine earth. The Missouri river is one of the most marked examples. This river conveys an enormous quantity of fine earth into the Mississippi, and through this river much of this earth is washed on into the Gulf of Mexico. It has been estimated that the quantity of earth carried into the gulf every year by the Mississippi river would be sufficient to cover one hundred square miles of territory to the depth of almost two and three-fourths feet. This quantity, however, enormous as it appears, is but a small proportion of the earth yearly moved by these rivers, for much of that which they carry must be left in those parts of their valleys which are at times overspread by floods. In New England we have one conspicuous example of the movement of material by a river.

Within the memory of men still living the Connecticut river has carried away some hundreds of acres of fertile fields formerly a part of the town of Hadley, while during the same time the meadows in the town of Hatfield have increased in area by about an equal amount. It is not, however, the rivers alone, nor even the rivers and streams, which move soil materials. The water which flows down our hillsides in violent storms is continually moving soil from higher to lower levels. This fact serves in considerable measure to account for the greater depth and fertility of the low lands, for it is the finer and better portions of the soils which are most likely to be carried downward. The deposit of fine earth in moderate quantities resulting from the overflow of the rivers and streams may be beneficial, but for the most part the operations of the farm should be directed rather to prevent than to increase the extent to which water transports soils.

45. *Water sorts materials* — Where water gathers in a large stream and moves rapidly it carries forward, as has been pointed out, both coarse and fine materials, even stones and rocks. These coarser materials, however, can be moved only while the current is rapid, and so as the stream moves on and gradually goes more and more slowly, these coarser materials will first settle to the bottom. As the current becomes still more slow, sand will be laid down — first the coarser sand, later the fine; while only when the water comes to rest will the finest earth which it carries be deposited. It has been found that water moving no more than about one-sixth of a mile per hour will still carry clay, and this constituent of soils is therefore laid down only when the water comes almost absolutely to rest.

46. *Moving ice* — Moving ice, in the form of glaciers, both grinds and moves materials, and this force has had more to do with the formation of the soils in Massachusetts and New England than any of the others. Our soils are practically all glacier formed. The glacier is a mass of ice moving slowly forward in obedience to the action of forces which are not yet perfectly understood. It should be remembered, however, that it is not moving in obedience to the law of gravitation. It is not ice sliding down hill. That makes an avalanche. At a period in the comparatively recent past the climate of the northern hemisphere must have been much colder

than it is at the present time, and during this period the ice and snow covered a large share of the northern half of our globe. In this country it extended about as far south as the latitude of the city of Philadelphia. This great sheet of ice moved in general toward the south with irresistible force. Even mountains could not stop it as it gathered behind them until it reached their summits, and then moved on. This sheet of ice was in many places of enormous thickness and bore upon the surface over which it moved with tremendous weight. The pressure upon the surface over which the glacier moved must have been equal, according to some authorities, to as much as two hundred thousand pounds to the square foot in some instances. Since the ice sheet had such enormous weight and thickness, and since ice is so much harder than water, the wearing action of the glacier was far greater than that of water. But just as the wearing action of water is increased by the rocks and stones that the great streams roll forward, so the wearing action of the glacier was increased by the rocks, stones, and sand which became bedded in the ice at and near the bottom. These rocks and stones like so many teeth cut and tore their way even through solid rock, and as they cut they were themselves of course crushed and ground. The parallel grooves to be found in many parts of New England on the surfaces of exposed ledges of rock must have been cut by glacial action. The glacier, however, not only broke and ground the rocks, it also carried onward the materials which it ground. These in some cases were pushed before it, in other cases they were bedded in the ice and moved on with it. This great sheet of ice was continually melting away at its lower or southern end, and, as the climate of the country gradually changed, becoming more and more warm, the limit of the ice was pushed farther and farther north, until, as is the case to-day, glaciers, save on high mountains, were confined to the northern part of the frigid zone. As the ice receded, the stones, the sand, and the finer soil which had been bedded in the ice came to rest, being dropped sometimes at the edge of the glacier, more often probably carried forward a greater or lesser distance in the stream of turbid water flowing out from beneath the ice. Practically all the soils of New England were formed during the ice age, and the same is true of a considerable

portion of the northern part of the United States. The same is true of the British Provinces. Material torn from the rock and transported by glaciers is almost everywhere found. Soils formed by this agency are known as drift soils. The soils of New England, then, are drift soils. The surface, as is well known, is very much broken; hills of moderate elevation abound, the soil in these hills is in many cases gravelly or sandy, and in almost all sections stones of various sizes are to be found. Drift soils vary enormously, both in the nature of the material comprising them, and in depth, elevation, and slope. We have in New England no extensive areas throughout which the soil is uniform. Infinite variety is the rule, save of course in the large river valleys, where there are tracts of considerable size level and fairly uniform throughout. Drift soils are comparatively raw. They have been produced chiefly by mechanical means. The glacier acted as a gigantic millstone, grinding and pulverizing the rocks. This pulverized rock, as a rule, contains fairly liberal amounts of potash, phosphoric acid, and lime, but these constituents are largely in such form that plants cannot make use of them. Before they become available they must be acted upon by the chemical agencies found in air and water. Drift soils contain as a rule but little organic matter. The presence of such matter is of great importance. It contributes largely to the improvement and enrichment of the soil.

47. *The action of wind* — In some parts of the world the winds have played an important part in soil formation. Wind acts chiefly in transporting materials, but in localities where it blows with great violence it gathers up and sweeps along even sand of considerable coarseness; and this sand, striking against rocks or other solid objects, slowly wears them away and is itself made finer. There is on record an account of a storm sweeping over a part of Cape Cod with such violence that the glass in some of the lighthouses was so roughened as to assume the appearance of ground glass. Its capacity of transmitting light was so much lessened that it became necessary to replace it. The lights of glass in the houses in some exposed localities in course of time become badly worn as a result of this action, and in some parts of the world it has been noticed that rocks are similarly worn.

This action of the wind, though it may have been important in some localities, cannot be regarded as of any value in this part of the United States. The action of the wind must be looked upon as injurious rather than otherwise. In exposed localities it frequently carries away a large amount of the finest and best portion of plowed fields, and the blowing dust is highly injurious both to plants and animals. The farmer, then, has to adopt methods whereby he may lessen this effect of the wind. The most effective among the various means which are practicable is to keep the surface of exposed fields protected by means of a crop.

XII — THE CHEMICAL ACTION OF AIR AND WATER.

48. *The air in its relations to soil formation* — The air is a mixture of gases, most important among which are nitrogen, oxygen, and carbonic acid. It is the two latter which play an important part in soil formation. As a result of their action many of the rocks are slowly weakened and finally crumble into soil. These are the chief agencies which are active in soil formation in localities which have not been subjected to glacial action, and in such localities the oxygen of the air, the carbonic acid, and the water cause the slow breaking up of the rocks. In the northern part of the United States the rocks, as has been pointed out (46), have been broken and ground chiefly by other agencies, most important in New England by the ice. But even where the rock is ground by other agencies the action of the oxygen and of the carbonic acid is useful. Oxygen is continually acting upon almost all classes of materials found in the soil. It combines with them to form oxids. One of the most familiar examples is the formation of iron rust, which is an oxid of iron (28). The oxids are without exception more soluble and more available than the original elements, and the usual result of oxidation is to cause the rock material oxidized to crumble. The metal iron cannot easily be pulverized and is not available as plant food, but iron rust (oxid of iron) is a powder and by combining with acid becomes available to plants. The carbonic acid of the air, which is readily taken up by water, then becomes a powerful solvent, *i. e.*, it has the ability

to dissolve many of their constituents out of certain kinds of rocks. When a part of a rock is dissolved it makes the rock weak and it crumbles much more readily.

49. *The chemical action of water* — The water with which rocks and soils are moistened and in which they sometimes lie plays an important part in disintegrating the rocks and in the formation of soils. It slowly softens some of the constituents of certain rocks and it dissolves others. Water unites chemically with constituents found in some rocks, forming a class of compounds known as hydrates. One of the best known examples of the formation of a hydrate by union with water is afforded by the slaking of quicklime. In this process the hard lumps of lime take up a large quantity of water, they became hot, and fall to pieces. Slaked lime is calcium hydrate. In nature the formation of hydrates is likely to go on much more slowly than when quicklime is slaked, but the process is similar in its results. When some of the constituents of a rock are changed into hydrates these constituents are likely to swell and to crumble. This must cause the rock to break down more readily. The ability of water to dissolve materials found in rocks or in soils is much increased by the presence of carbonic acid, and the water which we find in soils and rocks practically always contains carbonic acid. This carbonic acid may be taken from the air or it may come from decaying organic matter, which is always present in larger or smaller quantities in all soils. The action of the water upon rocks may seem slow, but through the countless ages it produces marvelous effects. The penetration of water into rocks and their gradual breaking up under its influence are universal. No rock can escape, though there are wide differences in the degree of rapidity with which rocks are thus destroyed. When one property of water fails to have an effect upon the rock another succeeds, and the combined action of the various agencies working in and with water is resistless.

50. *Air and water work together* — Some of the principal effects of air and of water have been pointed out in the two preceding paragraphs. It is now necessary to call attention to the fact that the air and the water generally work together. Moist air or air working upon rocks which are moist

has a far greater influence than dry air or air working upon dry materials. Iron will not rust if kept dry and in dry air. A splendid example illustrating this point further is afforded by the facts concerning the obelisk which a few years ago was brought from Egypt and set up in Central Park. This obelisk was presented by the Khedive of Egypt. It had stood for centuries in the dry air of Egypt and throughout that time it had been apparently entirely unaffected by the action of natural agencies. Its surface and the inscriptions it bore were perfect. Not long after it was set up in Central Park it was found that small bits were crumbling off from the surface and it was soon perceived that this fine relic of antiquity would be completely destroyed within a comparatively short time. In the dry air of Egypt, where it was never exposed to a temperature below freezing, the obelisk was unaffected by the agencies of nature. In the moist air of New York the rock absorbed moisture and when the absorbed water was converted into ice the rock crumbled.

51. *Weathering* — The breaking down of rocks under the combined influence of air, water, and frost is called rock weathering. As has been pointed out (46), the soils of the Northern United States were practically all mechanically pulverized by the action of ice. These soils, however, weather just as truly, in one sense, as rocks weather. The agencies air, water, and frost act upon the rock meal instead of upon the large rock masses. The effects are entirely similar. The exposure of our soils to the action of air and water and frost is useful. Such exposure is not needed, it is true, to pulverize the materials, but the effect in other directions is highly important. The soils of New England and of the Northern United States generally, which were ground in the first place by glacial action, must be ripened and improved by exposure to air, to water, to frost, and to other agencies which are spoken of in succeeding paragraphs (52, 53, 54, 55), before their constituents become available. It is true also, and this is important, that although the original grinding was done by the glacier, the effect of exposure to air, water, frost, etc., is to make particles of soil yet finer than they were left by the ice.

XIII — PLANTS AND ANIMALS AS SOIL FORMERS AND IMPROVERS.

52. *Living plants* — There are a few plants which are able to grow in sheltered places upon the surface of rocks and stones. These plants attach themselves firmly to the rock and take out of it a part of their food. The lichens and the mosses are of this class. The rock beneath such plants is gradually softened and breaks up into soil under the action of other natural agencies all the more quickly because these plants have first grown upon them. The higher plants, such as the grasses, trees, and shrubs, also play an important part in forming and improving soils. Their roots grow into minute crevices and cracks in the rock, and as these roots increase in size they break off pieces which may be large or small. Moreover, the small and delicate feeding roots, *i. e.*, the roots which gather food for the plant, secrete an acid which keeps their surface moist, and where this acid acts upon the rock or upon the fine particles of soil, which is chiefly pulverized rock, it dissolves something out of the rock. The result is, as has been pointed out in speaking of the action of water (49), that the rock is softened and gradually crumbles. Living plants, therefore, play an important part, both in breaking up rocks, making particles of soil finer, and in dissolving some of the constituents of both.

53. *Organic matter* — Organic matter, as will be remembered (36), may come either from plants or animals; but practically all the organic matter which we find in soil has come from plants. This organic matter comprises a large part of some soils such as peats and mucks, and it is present in considerable quantity in all fertile soils. Where organic matter is present it retains a considerable quantity of water, as it acts in some respects like a sponge. It has already been pointed out (40, 49) that the action of all natural agencies is most energetic where water is present. Further, the rotting of organic matter results in the formation of carbonic acid and, it may be, of other acids and compounds, and these when dissolved in water greatly increase the effect which it has in breaking up rocks and improving soils.

54. *Humus* — The name humus is used to designate that portion of

the organic matter found in soils which is in a partly rotted condition. The roots and stubble of crops, stems, leaves, etc., which are plowed in and the farmyard and stable manures applied to soils furnish large quantities of humus. Such materials as have just been named, if completely rotted as they would be if exposed to the full effects of the air, would not form humus. When vegetable matter is fully rotted we have left only the mineral elements which were found in it. Humus is more abundant in virgin soils than in those which have been long cultivated.

55. *Living animals* — Among the various animals which have played a part in soil formation or in soil improvement the common earthworm and the ant are the most important. The earthworm is often found in large numbers in fertile and moderately moist soils. These worms burrow, often to a considerable depth, and into these burrows the air and the water find their way more freely than before, and this better exposure of the soil to air and water results in its improvement. The earthworm in opening its burrow swallows the earth, and the earth swallowed passes through the worm and is finally thrown out in the form of castings at the mouth of the burrow. As a result the particles of earth grind the one on the other and are made finer. They are also soaked in the digestive fluids of the animal and in part dissolved. The earth which passes through the body of the worm, then, is greatly improved from the standpoint of the farmer, having been made finer and to a considerable extent more soluble. Darwin found by observation that in fertile soil the earthworms may bring up so much material as to cover the surface to the depth of about one-fifth of an inch yearly. Once in five years, then, an inch of new and finer and better material is left upon the surface of the field, unless, as is often the case, it is washed by the rains or melting snows to lower levels. In level fields, as Darwin pointed out, the upper portion of the soil is thus continually made new. Lime spread upon the grass lands appears to sink into the ground. He called attention to the fact that in reality it does not sink, it is simply covered by the fine material which worms bring up from below. Further, earthworms feed upon leaves or partly decayed vegetable matter and they often carry these materials down into their burrows. They thus mix vegetable matter with

the soil and this, as has been pointed out (54), is useful. As a consequence of the better exposure of the soil to air and of the mixture of organic matter with soil, it is in many cases made more mellow. It crumbles and pulverizes better when plowed, and this also may be important. Thus it will be seen that the humble earthworm in many ways plays an important part in soil improvement.

As a result of the work of ants in soils effects are produced which are in some respects similar to those produced by earthworms. The ant, however, does not swallow earth and therefore does not pulverize the soil as does the earthworm. Other animals which have a relation to soil formation are the crayfish, moles, field mice, and other burrowing animals. The effects produced by these animals, however, are much less important than those which have been mentioned. In the great economy of nature the action of these animals is doubtless finally useful, but the farmer of to-day seeks rather to avoid than to encourage the action of these animals.

XIV — SOILS CLASSIFIED ACCORDING TO METHOD OF FORMATION.

56. *Classes named* — All varieties of soils may be divided into two great classes according to the method in which they are formed. These classes are sedentary and transported. Sedentary soils are those which are formed by the weathering of rocks in the place where the soil is found, or from the accumulation of organic matter, as in swamps or marshes. Transported soils are composed of materials which have been moved by some agency, such as water, ice, or wind, to the place they now occupy.

57. *Sedentary soils* — There are two kinds of sedentary soils, viz., residuary deposits and cumulose soils. The soils of the first of these two kinds directly overlie the parent rock and have been formed by its slow weathering. They have usually lost some of their soluble constituents. These have been washed away with the rain and snow water which have soaked through them. *Residuary deposits* are often composed largely of clay and are generally of a dull color such as brown or dark red. These soils are not generally very deep, for as the rock weathers the soil which lies at the top protects the rock beneath. Such soils vary widely in fertility

according to the rock from which they have been formed. The constituents which they contain are generally in large proportion available because they have been so long exposed to weathering agencies (51). *Cumulose soils* consist largely of organic matter which has come from the gradual, partial decay of the plants which have grown in the swamp or marsh where the soil is found. In almost all cases, however, some earth washes into such swamps or marshes from surrounding higher land and therefore these soils contain larger or smaller quantities of earthy matter. The soils which are commonly spoken of as peat or muck belong to this class. Such soils are rich in humus and nitrogen and if they can be well drained they may become very productive, especially if they contain considerable earth mixed with the organic matter.

58. *Transported soils* — Transported soils are divided into four classes: colluvial, alluvial, æolian, and glacial or drift.

59. *Colluvial soils* — Colluvial soils are composed of materials which in obedience to the law of gravitation have fallen from a higher to a lower level. Materials carried down from mountains by avalanches, materials which have fallen from the face or from the tops of cliffs, etc., go to form soils of this class. Such soils may contain both fine earth and stones and rocks of various sizes. The area of soils of this class is comparatively small and they are unimportant in most of the New England and northern states.

60. *Alluvial soils* — Soils of this class are formed from materials which are carried by water and which finally settle out of the water. These soils commonly show more or less distinct layers or strata, coarser and finer layers alternating with each other. Because of this peculiarity alluvial soils are said to be stratified. The materials found in alluvial soils are for the most part finely pulverized. Such soils vary widely in depth. In the upper portions of the river valleys or near the high lands on either side of the valleys such soils are shallow; while nearer the larger rivers and streams and especially near the mouths or at the mouths of large streams such soils are often of very great depth. The surface of alluvial soils is nearly level and generally comparatively smooth and the soil will contain no large stones. The alluvial soils are commonly the most fertile soils which are to be found

in any given drainage basin, *i. e.*, in an area which is drained by one river and its branches. This is so because the running water gathers up and moves the finest portions of the soil most freely. Alluvial soils, then, are generally good soils. There are, however, some exceptions. Some of the older alluvial soils contain a large proportion of moderately coarse sand and these soils are not very productive. The plain lands in the vicinity of Westfield and Agawam are of this kind. On the other hand, the meadows of Sunderland, Hadley, Northampton, and other parts of the Connecticut valley are very fertile. When an alluvial soil is composed wholly of very fine materials and does not show distinct layers of different degrees of fineness it is known as *loess* or *water loess*.

61. *Æolian soils* — Æolian soils, practically speaking, are those which are composed of material transported by the wind. In some parts of the world these soils are of great fertility but in New England the æolian soils are generally composed of sand and are of low fertility. The sand dunes of the seacoast and of some parts of the Connecticut valley are examples of such soils. They are on the whole entirely without agricultural importance.

62. *Drift soils* — Drift soils, it will be remembered, are formed by glacial action (46). They are usually composed of a mixture of stones of various sizes with more or less finer material. We find enormous variation within this class. In some places drift soils are composed very largely of stones, in other places they may be mostly sand or clay, and between these extremes we find almost every imaginable mixture of stones, sand of different degrees of fineness, and clay. The materials making soils of this class are not arranged in regular layers. On examination we find a heterogeneous mixture of the materials. These soils vary very widely in depth and the surface of the country covered by them shows the utmost diversity. In some places the drift is only a few inches in depth, in other places it may be several hundred feet. In some places we may find comparatively level areas of considerable extent, but for the most part the surface covered by drift is very hilly. These variations in depth and in the nature of the surface are mainly due to the nature of the underlying rocks, on which the

receding ice left the soil. At the tops of hills and mountains they are generally shallow. In the valleys they are more likely to be deep. It follows from what has been said that drift soils vary widely in quality and in value for farming purposes. The chief causes of this variation are:—

(*a*) Such soils have been formed from many different kinds of rocks and the nature of the soil is closely dependent upon the kind of rock or rocks which have been ground up to make it. Among the best drift soils are those composed largely of materials derived from limestone or marble.

(*b*) The degree of fineness or the proportion of fine earth. The drift soil which contains a fair amount of clay and other fine materials is likely to be fairly productive, but if composed of coarse sand or sandy gravel it will usually be unproductive.

(*c*) *Depth* — Where the distance from the surface of the drift to the bed rock is small the soil is generally comparatively unproductive. As a rule the deeper the drift soil the more productive it will be.

XV — THE COMPONENTS OF SOILS.

63. *Classes of soil materials named* — Practically all of our productive soils contain the following kinds of material : sand, silt, clay, and humus. The proportion of these in different soils varies widely and affects the value of the soil for agricultural purposes in very marked degree. The best soil is usually one which contains each of these kinds of material in fairly even amounts.

64. *Sand* — Sand is composed of granular particles of rock which are sufficiently large to be readily seen by the naked eye. As a rule these particles consist chiefly of quartz, a mineral which is a compound of silica. Quartz is the hardest of the minerals found in rocks. It is sufficiently hard to scratch or cut glass and it is because it is so hard that it has not been ground finer. It is only very slowly acted upon by the agencies which cause weathering. It is very insoluble and contains exceedingly little plant food. Sand is the heaviest of the different classes of material found in soils. Sand is divided into different grades according to the size of the particles. The grades now commonly distinguished are four in number,

known respectively as coarse sand, medium sand, fine sand, and very fine sand. The proportion in which sand of these different grades is found in soil greatly affects its value, chiefly because of its relation to the temperature of the soil, to the amount of water it will hold, and to its adaptation to different crops.

65. *Silt* — Silt is that part of the soil which consists of particles intermediate in size between the finest sand and clay. Several grades are distinguished, depending upon the size of the particles. The most usual division is into two classes — silt and fine silt. Silt is composed of exceedingly fine bits of rock of many different kinds. It will commonly be found to contain a considerable proportion of the available plant food of the soil. For this reason as well as because silt enables the soil to hold water and allows water and air to move through it in such a way as to favor productiveness, silt must be regarded as one of the most valuable constituents of soils.

66. *Clay* — Clay, in the sense in which the word is used in agriculture, is made up of those particles of the soil which are so small as to be separately invisible to the naked eye. Clay is entirely without grit. Even when rubbed by the finger tips in the palm of the hand we feel simply the mass of clay ; we cannot feel a *single* particle. Some authorities state that all those particles of the soil which are below 0.0002 of an inch in diameter are to be considered as clay. Clay may be derived from various kinds of rock minerals which have been extremely finely pulverized. It is, however, most usually composed largely of silicate of alumina. Clay is so fine that its particles will remain suspended in water for a long time. They do not settle until the water becomes still. Clay absorbs a large amount of water. The particles are so small that they lie very close together. The spaces between these exceedingly small particles are very minute. For this reason clays are comparatively impervious both to air and water. If water be poured upon the clay it remains upon the surface a long time, soaking into the clay only with extreme slowness. When moist, clays are very adhesive and if they are stirred, as with the plow, harrow, or hoe, they cannot be made fine but turn over in sticky clods. When these clods dry they be-

come hard and rock-like and can be broken into powder only with considerable difficulty. Soils in which clay is abundant, because of the peculiarities which have been mentioned, are apt to be wet and hard to work. They are also cold.

67. *Humus* — The vegetable matter which we find in soils is not all of it true humus. We usually find entirely unrotted vegetable matter which comes from the most recent crop or manure, and between such material and the true black or brown humus we find matter in every intermediate stage of decay. Taken as a whole, the organic matter which we find in soils is more or less porous and sponge-like in character. It soaks up and holds water somewhat as a sponge might do. The color, especially of that portion of the vegetable matter which has been changed by partial decay into humus, is dark, and the soils which contain most humus are, therefore, as a rule darkest in color. It is well known that dark colors are more favorable to the absorption of heat than light. It is equally true that organic matter parts with heat quickly. We find, therefore, that thoroughly drained muck or peaty soils, or any soils which are very rich in organic matter, may become very hot during sunshine because of their color, but at night or in cloudy weather they quickly part with their heat and become cold. This great variation in temperature is likely to be unfavorable to crops. The organic matter which we find in most soils has a more or less fibrous character ; and these fibers, consisting in many cases of roots, stems, and leaves mixed with soils composed largely of clay or silt, serve to separate the particles of such soils and thus render them somewhat less cohesive and difficult to work. When mixed with sandy soils, on the other hand, organic matter, taking up water as does a sponge, helps to keep such soils more moist and in better condition to produce a crop. The mixture of organic matter, both with soils which hold too much water (clays) and with those holding too little (sandy soils), greatly improves them. Further, the organic matter of the soil contains a large amount of food for plants. It comes from plants, and contains everything which the plants need, and when the organic matter rots these constituents become available for the next crop. Still further, as organic matter rots it produces acids

(53) which, being absorbed in the water of the soil, help dissolve rock and soil materials, gradually rendering them more available.

XVI — AGRICULTURAL CLASSIFICATION OF SOILS.

68. *The commoner kinds of soils* — To the farmer the method of formation of the soil is of less practical importance than the knowledge of those properties of the different soils he meets which affect its value for the production of crops. The agricultural classification of soils is chiefly based upon these properties, and these properties in turn are dependent almost wholly upon the relative proportions of sand, silt, clay, and humus which

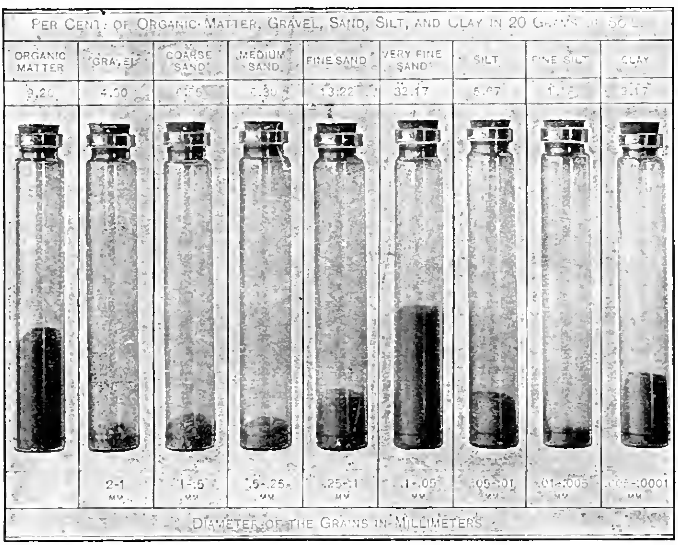


FIG. 3. Loam; will work nicely and produce crops of all kinds, because it contains the different grades of sand and silt, as well as organic matter and clay in suitable proportions.

the soil contains. The most useful agricultural classification of soils, then, is based upon these proportions. We have then, first, sandy soils, clayey soils, and humus soils. These are not necessarily composed respectively entirely of sand, of clay or of humus; they are simply soils in which the constituent which gives the name predominates. We have, further, a

considerable number of soils in which these constituents are present in more nearly equal quantity. To all of these the name loam is given. We understand by loam a soil which consists of a fairly even mixture of sand, silt, clay, and humus. According as the one or the other of these constituents is present in larger or smaller amount we find a great variation in loams. We have, in other words, many kinds of loam. The different kinds of loam have received names which indicate their general character. We ordinarily distinguish at least the following kinds: heavy clay loam, clay loam, loam, sandy loam, and light sandy loam. In any of the different kinds of loam the proportion of humus may vary quite widely. This may easily be indicated by adding a few descriptive words such as "rich in humus," "poor in humus," etc. Our soils in some cases contain more or less stones of varying size, in which case they are apt to be somewhat gravel-like in quality. This gravel in many cases has much the same effect upon the character of the soil as sand. In some cases, however, the gravel contains a considerable amount of clay.

69. *The less common soils* — Besides the soils above named, we occasionally meet with soils which possess quite unusual constituents, or common constituents in unusually large quantity. Such soils are commonly designated by the name of the unusually abundant constituent. Among such soils some of the more common are marl, calcareous soils, alkali soils, salt marsh soils, and fresh marsh soils.

70. *The amount of sand in different loams* — The proportion of sand in any of the different classes of loams varies within certain limits. If the sand be fine more must be present in order to throw a soil into any one of the classes above heavy clay loam than if it be coarse. Nevertheless, most authorities classify loams according to the approximate amount of sand contained in them, and the following statement is generally accepted: —

Heavy clay loam contains from 10 to 25 per cent. of sand.

Clay loam contains from 25 to 40 per cent. of sand.

Loam contains from 40 to 60 per cent. of sand.

Sandy loam contains from 60 to 75 per cent. of sand.

Light sandy loam contains from 75 to 90 per cent. of sand.

If a soil contains less than about 10 per cent. of sand it is clay or clay-like; if more than 90 per cent. of sand is present then the soil is a sand or is very sandy.

XVII — LIGHT AND HEAVY SOILS.

71. *Light soils* — Light soils in the agricultural sense of the word are those which have little cohesiveness, which readily break into a meal-like mass on being worked. Such soils work easily; the labor of cultivating them is light, hence the name — light soils.

72. *Heavy soils* — Those soils which have great cohesiveness, those which, particularly when moist, tend to cling together, are known as heavy soils. When worked with a plow such soils tend to turn over in clods, they adhere to the plow or to other tools used in them. The labor of cultivation is difficult or heavy, and hence the name — heavy soils.

73. *The terms light and heavy soils have no relation to weight* — The words light and heavy as applied to soils in the ordinary agricultural sense have no relation whatever to the absolute weight of soils. Indeed, those soils which weigh most (sands) are lightest, while clays which weigh far less are the heaviest of soils.

XVIII — LEADING CHARACTERISTICS OF THE DIFFERENT KINDS OF SOIL.

74. *Sandy soils* — Soils which contain 80 per cent. or more of sand are generally designated sandy. As a class such soils have but little agricultural value, but there is a wide variation in the degree of suitability to crops with the size of the particles of sand. If nearly all the sand is of the finest grade, a sandy soil may have considerable value. As a rule, however, sandy soils hold but little water and crops growing on them suffer in hot, dry seasons. Such soils are poor in plant food and have but little capacity to retain the soluble portion of manures or fertilizers. Soluble compounds are likely to leach through them with the water, and hence such soils are often called hungry or leachy. If a sandy soil be enriched in organic matter it is much improved, as the latter both helps to hold water and supplies plant food. Such matter is best supplied by the growth of such

crops as cow peas or clovers, which take a part of their food from the air. Sandy soils are warm and in some cases contain large amounts of lime, potash, and phosphoric acid, as for example the green sands of New Jersey, which are very fertile. Sandy soils as a class work easily. Soils of this class are well suited for sewage irrigation (266), for where this is practiced both water and plant food are supplied in very large amounts and soils are made exceedingly productive.

75. *Clay soils* — The soils which are called clays must, according to some authorities, contain at least 60 per cent. of clay. The particles of such soils are excessively fine. When wet such soils are very tenacious; when dry they become hard and rock-like and cannot easily be crumbled or broken. In long continued hot, dry weather minute crevices and cracks open in the clayey soils, letting in the air, which dries and injures the roots, and sometimes breaking the roots. Clayey soils are comparatively impermeable to water and unless a more open soil, such as sand or gravel, is found underneath at not too great a distance from the surface, a clayey soil is likely to be very wet and cold. If the proportion of clay is not too much above 60 per cent. the soil may be quite fertile and yield good crops, especially of grass and wheat. If it amounts to 80 or 90 per cent. the soil will be practically unfit for use in agriculture. The crops on clayey soils are especially likely to suffer in both wet and dry seasons. Many soils which appear clayey contain little real clay, being composed largely of silt. Such soils are much more workable and of far greater value than the true clayey soils.

76. *Humus soils* — The peats and mucks are the best examples of soils of this class. The proportion of humus in such soils may vary between about twenty-five and one hundred per cent. Peat is formed by the partial decay and modification of vegetable matter under water. It is compact and contains but little earth. Peat is intermediate between vegetable matter and coal. In course of time it would become converted into coal. In a certain sense it is young coal, and if the changes which will make it coal are well advanced it has little agricultural value. If, on the other hand, these changes are less advanced and especially if there is a considerable mixture of

earth, the peaty soil on being drained and rotted may become quite productive. Muck is formed where the vegetable matter is alternately under water and exposed to the air as the water level falls. It is less compact than peat, and is usually more admixed with earth. It is in a more advanced condition of decay, and on being dried it can easily be pulverized. After drainage mucky soils usually become highly fertile and productive.

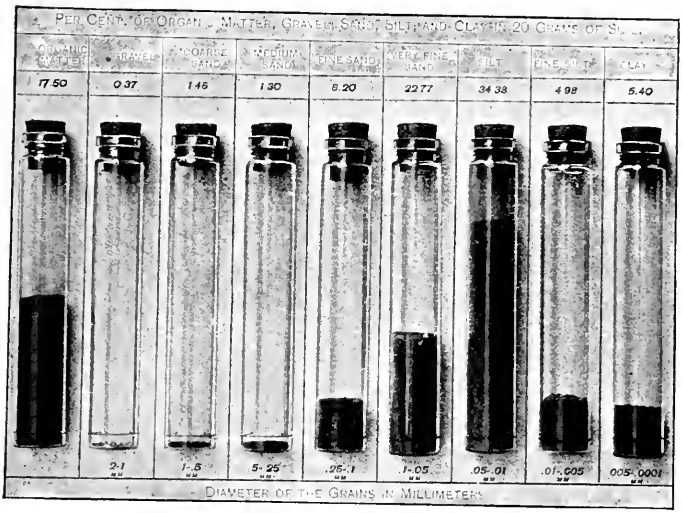


Fig. 4. Heavy Loam; small proportion of sand, but organic matter and silt more abundant; holds water, usually cold, and will form crust and crack in dry seasons; needs aeration.

77. *Heavy clay loam* — Heavy clay loams have the ability to hold a large proportion of water and in dry weather water moves up through them from the body of soil water below, much as oil moves up the wick of the lamp. The crops on this soil, if it is properly worked, are not likely to suffer from drouth. Soils of this class are compact and most of the particles fine. The air does not circulate through them freely because the spaces are too small. Such soils, then, are poorly aerated and need careful working to promote aeration. The supply of plant food in soils of this class is comparatively large, potash especially is likely to be relatively abundant. Such soils, moreover, have good retentive capacity. Soluble plant foods

are less likely to be washed through them than in the case of soils of other classes. Heavy clay loams are cold, usually moist and heavy. They are somewhat likely to form a crust at the surface in dry weather and to crack. Careful cultivation will, however, generally prevent injury from these causes. Tender crops are likely to winter kill on soils of this kind. They are in general best suited to such crops as grass and wheat.

78. *Clay loams* — Loams of this class have most of the characteristics of the heavy clay loams but in somewhat lesser degree. Their capacity to hold water and to conduct water from below upwards is still great. They are rather compact and are not particularly well aerated. They are somewhat likely to form a crust or to crack and need careful working. The supply of plant food, especially of potash, is usually good. The ability to retain soluble plant food compounds is good. The soils are cool and in general safe soils to work because the danger of injury from drouth is small. They are excellently suited to such crops as grass and wheat, and, if the drainage is good, will give good results with oats, onions, and some of the fruits, among which the apple is the most important.

79. *Loam* — In loam all the various qualities are in good balance. Their ability to hold and conduct water is good, the supply of food is likely to be good, and their ability to retain soluble food compounds is considerable. Loams allow the air to circulate more freely than the heavier soils, and they can be worked much more easily. They have comparatively little tendency to the formation of a crust or to cracking. They are well suited to almost all crops. Grass, wheat, oats, onions, beets, corn, potatoes, squashes, and fruits will all do well upon loams, as also will clovers and alfalfa. Those crops having their orig'n in the tropics and especially liking heat are the only ones which it is best to put upon lighter soils. When, however, it is desirable to bring the crop to maturity as early as possible it is commonly best to select a soil containing more sand.

80. *Sandy loam* — Soils of this class have capacity to hold only a moderate amount of water and they do not conduct water from below upwards as freely as do the heavier soils. They are well aerated, light, and easy to work. They are not likely to form a crust or to crack. The

supply of plant food is generally only moderate and they hold soluble food compounds less effectually than the heavier soils. On soils of this class there is greater danger of injury to crops from drouth than on those containing less sand. Such soils are warm and well suited for rye, potatoes,

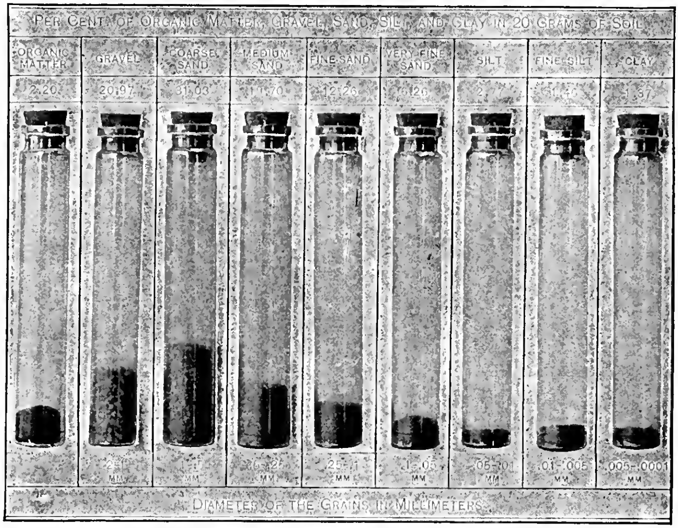


FIG. 5. Light Loam; contains so large a proportion of the coarser grades of sand that it is very light and easy to work; will not hold water nor soluble elements of manures well, but is warm and will give early crops.

corn, most of the common garden crops, turnips, squashes, melons, and tomatoes. They are also very well suited to clover and alfalfa. Such soils are likely to bring crops to maturity early, and in cases where this is desirable they may be preferable to soils which contain less sand.

81. *Light sandy loams* — Loams of this class have but little capacity to hold or conduct water. They are not, therefore, safe soils, since crops are quite likely to suffer or fail in hot, dry seasons. Such soils are perfectly aerated, they do not form a crust or crack, and are very easily worked. The natural supply of plant food is usually comparatively small and the ability to hold soluble food compounds is also small. These soils are warm and are especially suited to such crops as particularly need heat, among

which may be mentioned melons, tomatoes, beans, cow peas, and crimson clover. Alfalfa when once started will do well upon these soils. They are of course suited especially to all early crops.

82. *Marl* — This is a kind of soil which is derived chiefly from shells which have gradually been broken up and disintegrated. These shells are composed of carbonate of lime, which is therefore always abundant in marls. This carbonate of lime is always mixed with sand, clay, or silt. The proportion of such earthy materials varies widely. Marls are not fitted for culture. They are of value as manure for soils which need lime, and if they contain considerable clay they may be particularly valuable for the lighter soils, as the clay will give these soils capacity to hold more water. Moreover, such soils are generally comparatively poor in lime.

83. *Calcareous soils* — Soils of this class are derived from rocks which contain lime, such for example as limestone and marble. The gradual disintegration of such rocks usually furnishes a soil rich in lime, although in some cases much of the lime becomes gradually soluble and is washed away. Soils in limestone regions, however, generally rank high in fertility. (62*a.*)

84. *Alkali soils* — In that part of the United States which lies between the Missouri river and the Rocky Mountains and in a few other localities there are wide areas which naturally produce only a very scanty growth of vegetation. This district was formerly designated on the map "The Great American Desert." It has been found that the soils in this region contain abundance of food for plants. They are unproductive because they contain very large amounts of alkali salts. The most abundant and the most injurious of these salts in most places is carbonate of soda. Such land cannot be profitably cultivated unless the carbonate of soda can be removed or changed into other compounds. Abundant irrigation combined with thorough drainage will wash the carbonate out of the soils since it is very soluble; and after such irrigation alkali lands often become exceedingly productive. Hilgard has pointed out that if such land receives an application of common land plaster to the amount of a few hundred pounds per acre the acids and bases change places, with the result that sulfate of soda

and carbonate of lime are formed. The sulfate of soda is not injurious and alkali lands are often rendered productive by this treatment.

85. *Salt marshes* — The soil of the salt marshes found along our seaboard exhibits wide variation. The constituents abundantly found in these soils are clay, silt, and humus. Near the larger streams flowing through such marshes the soil generally contains considerable clay and silt. At a distance from these streams the proportion of clay and silt becomes small and that of humus greater. In many places where the soil is chiefly humus the handle of an ordinary hand rake can easily be driven down into the soft and wet soil to its full length. All salt marshes are subject to occasional overflow by salt water; and these soils contain large amounts of common salt as well as other salts which are left in them by the sea water. The vegetation found on these marshes is entirely different from that usually found on uplands. The soils of these marshes contain the various elements of plant food in large amounts; and they can be made very productive by thorough drainage and careful working, if steps are taken through the construction of dikes or embankments to prevent overflow by salt water. Those parts of the marsh where silt and clay are more abundant in the soil become more valuable for general purposes than those portions where these constituents are present only in small amounts. When reclaimed the salt marshes become valuable for the production of grass and onions on the portions containing more earthy matter, and for cranberries on the more mucky portions.

86. *Fresh marshes* — The soil of our fresh marshes is composed largely of muck and peat. The proportion and nature of these constituents vary widely in different marshes or in different parts of the same marsh. These soils are sometimes almost wholly organic in origin, but oftentimes considerable clay and silt are mixed with the organic portion. The soils of these marshes are usually deep and contain a large amount of the elements of plant food. If the proportion of silt is fairly large, such soils after drainage become very valuable for many of the farm crops, especially grass and celery. With partial drainage those portions of these soils which consist more largely of muck or peat become very valuable for cranberries, after being covered with sand.

XIX — PHYSICAL CHARACTERISTICS OF SOILS.

87. *Why these are important* — Under the subject Physical Characteristics are to be considered those peculiarities of soils which affect their weight and structure and their relations to heat, water, air, other gases, and electricity. A knowledge of those peculiarities of soils which influence their temperature and moisture must clearly be of great importance, because the temperature and the moisture greatly affect the growth of crops. The physical characteristics of a soil are determined chiefly by its natural character. They can be somewhat improved and modified by man, but are not to any very great extent under his control. It is highly necessary in selecting a farm or soil for a particular crop to secure the right physical characteristics. The productive capacity of soils is undoubtedly more often determined by their physical peculiarities, in so far as these affect temperature, water supply, and the amount of air contained, than by their chemical composition. The deterioration of soils, according to Snyder, is not usually due in so great a degree to a loss of plant food as to a change in physical conditions. Thus, for example, as a result of cultivation a soil may gradually become closer and more retentive until at last it holds too much water and contains too little air, and as a result bears smaller crops. Or, it may be that under a certain system of management it will gradually lose its ability to hold water and plant food and will become less productive for these reasons. Soils invariably give better crops when in a mellow, crumbly condition than when either excessively fine or lumpy. It must be evident that a knowledge of the conditions in soils which are most favorable to plant growth is essential to produce the best results.

88. *Important physical characteristics* — The more important of the peculiarities of soils which need study in order to throw light upon their value are the following :

1st. Weight and specific gravity.

2d. Structure and color.

3d. Relation of the soil to water.

4th. Relation of the soil to heat.

5th. Relation of the soil to air and other gases.

6th. Relation of the soil to electricity.

7th. Capacity to hold dissolved solids.

89. *Weight and specific gravity* — Soils vary greatly in weight, and as a general rule the coarser the particles the heavier the soil. The average weight of surface soil is usually about 75 to 80 pounds per cubic foot. Pure sand may weigh 110 pounds and peat only 35 to 50 pounds per cubic foot, and between these extremes we have every possible variation. The richer the soil in organic matter, other things being equal, the lighter it will be. Subsoils are as a rule heavier than surface soils because they contain less humus. The specific gravity of soils also varies widely. The average for surface soils is about 1.2 and for subsoils about 2.0. This means, since specific gravity indicates weight as compared with the weight of an equal volume of water, that surface soil is about 1.2 times as heavy as water and subsoils about twice as heavy. The specific gravity of soils is less in proportion, as they contain more air. The presence of porous materials for this reason decreases the specific gravity. Organic matter is the most porous of the common constituents of soils. If, therefore, it is found that the specific gravity of a soil is low we may usually safely conclude that the soil is rich in humus; but if the specific gravity is high we conclude that the soil is poor in humus.

90. *Color* — The color of a soil depends upon its composition and is therefore a valuable indication as to the nature of the soil. Humus, which is dark brown or black, causes soils to be dark-colored when moist, dark grey when dry. Iron oxid is the chief coloring matter in all reddish soils, while in the blue clay soils the color is due to the presence of a compound of iron and sulfur. The color of the soil is of importance only as it influences the absorption of heat. Materials of dark color absorb a much larger proportion of the heat from the sun than those which are light in color. The light-colored soils reflect much of the heat instead of absorbing it. It should be remembered in this connection that it is the color of the surface soil only that affects the absorption of heat. A soil naturally light-colored can be made to absorb heat by scattering any dark-colored powder over the

surface. Other things being equal, a soil with a dark surface will be found to be about 8° warmer than one with a light-colored surface during the hours of sunshine. Such a difference may affect the germination and growth of a crop in a marked degree. All other things being equal, seeds germinate more quickly and crops come forward more rapidly on soils of a dark color than on those which are light in color.

91. *Structure* — The structure of a soil is of the greatest agricultural importance because it influences the movement of air and water in the soil and the results of cultivation. The structure of a soil depends upon the size and shape of the soil particles, both of which influence the way in which these particles pack. Where the particles are large and uniform in size the interspaces (*i. e.*, spaces between the particles) are large and constitute a considerable portion of the bulk of the soil. If the particles are smaller the interspaces are smaller. With particles of uneven size the soil packs more closely because the smaller fragments fill in the spaces between the larger particles. If the soil particles are angular or flattened they pack more closely than if rounded. A good road cannot be made from round cobblestones. These will not pack. Broken stone will pack closely and makes a firm and permanent road. Although most of the particles in the soil are comparatively fine, the principle is the same. A soil composed of rounded particles does not pack and form a crust. Both too open a structure and too great compactness are undesirable. The structure of the soil should be such as to allow water from rains to pass downward through it with moderate rapidity. It should, however, be sufficiently compact to prevent too rapid downward movement of such water. The structure of the soil has an intimate relation to the total amount of surface of its particles. The finer the particles the greater is this surface. It has been found by calculation that the total surface of all the particles in a cubic foot of fine soil may amount to two and one-half to three acres. The total surface of all the particles in the soil of one acre of land to the depth of one foot may therefore amount to more than 100,000 acres. In coarse sands and gravels the total surface is much less. The agencies which dissolve plant food act mainly on the surface of the particles of the soil, and therefore the greater the total

amount of surface exposed to the action of air and water and the acid in the roots of the plants, the greater the amount of food which is rendered available. The fact that solubility is affected by the amount of surface exposed to the action of the solvent has been made very evident by the results of an experiment with a glass bottle. This bottle was filled with water and was boiled for a week, at the end of which time it was found that only two grams of the glass (about one-fifteenth of an ounce) had been dissolved. The bottle was then ground into a fine powder and this powder was boiled for a week, when it was found that one-third of the total weight had been dissolved. Within ordinary limits the greater the proportion of soluble constituents the more productive the soil. It therefore follows, other things being equal, the finer the soil the more productive it will be. There is, however, such a thing as excessive fineness. Soil holds water, as a rule, in proportion to the amount of surface of all its particles, and when the particles are excessively fine, as in clay, so much water is held in the soil as to render it unfit for plant growth. Investigations have shown that no crop will flourish in a soil which contains less than about 1,700,000,000 particles to the gram (about one-thirtieth of an ounce). Grass and wheat are found to do best in soil containing as many as 14,000,000,000 particles to the gram. The number of particles in a given bulk of soil indicates in a general way its suitability for different crops. Good corn land should be sufficiently fine to contain from 6,000,000,000 to 7,000,000,000 particles to the gram. The arrangement of the particles in the soil also has a close connection with its agricultural value because it affects the degree of compactness and the relation to water. No satisfactory method of determining the arrangement has yet been discovered. Warrington says that it is not best that the soil consist entirely of separate solid particles, and points out that where some of the particles cling more or less closely together, making what he calls compound particles, conditions are more favorable to the production of good crops than when each solid particle is separate.

XX — RELATION OF THE SOIL TO WATER.

92. *The amount of water required by crops* — All plants are dependent for their existence and development upon the continuous and sufficient supply of water throughout their entire period of growth, and the total quantity of water required is very large (14). For each pound of dry matter in the crop it is estimated that from 250 to 400 pounds of water must be furnished to the plant. In an experiment in New York in producing a pound of dry matter in oats 522 pounds of water were used. For a pound of dry matter in corn, 234 pounds of water; for a pound of dry matter in potatoes, 423 pounds of water; and it was calculated that to produce a crop of 450 bushels of potatoes to the acre 1,310 tons of water were required. Throughout growth, water is continually passing through the plant, being taken into the roots and thrown off chiefly through the leaves. This process of throwing off water through the leaves is known as transpiration. The quantity of water used by large crops of different kinds varies quite widely. It has been calculated that: —

One acre of wheat exhales an amount of water equal to a layer over the entire surface 1.8 inches deep.

One acre of clover, 4.5 inches.

One acre of cabbages, 21.6 inches.

One acre of corn, 6 inches.

In addition to the water which is exhaled by the crop there is a constant loss of water by direct evaporation from the soil, a loss which becomes very great in hot, dry weather, especially if such weather be accompanied by drying winds. The soil then has to meet both the demand of the crop and this loss by direct evaporation. An attempt was made a few years ago in the Iowa Experiment Station to determine the total of water removed from the soil through these two agencies. The results were as follows: Per ton of clover hay the loss of water amounted to 1,560 tons. If spread over one acre this would amount to a layer 13.7 inches deep. Per ton of air-dry corn fodder, the loss was 570 tons; for one acre a layer 5 inches deep. Per ton of oats and straw, the loss was 1,200 tons; for one acre a layer 11

inches deep. For 450 bushels of potatoes the loss was 1,310 tons; for one acre a layer 12 inches deep. For one acre of pasture 3,223 tons, a layer 28 inches deep. The average rainfall during the season occupied by the growth of some of these crops is often less in many parts of our country than the loss of water which these experiments indicate; and even where the average is not less we frequently have seasons during which it is less. The average rainfall in Amherst, Mass., during the five months, May to September inclusive, for the past sixty years has been about 20.25 inches. This would be sufficient to cover the total loss of water indicated for most of the crops above named, but in 1870 the rainfall during these months amounted to only 11.5 inches; in 1881 it was less than 15 inches; in 1888 it was 13.5 inches; in 1893 it was 17.25 inches; in 1894, 13.5 inches; and in 1895, 17.0 inches. As a rule the rainfall decreases as we go west from the Atlantic seaboard. It is considerably less at Albany than at Amherst, much less at Buffalo than at Albany, less in Chicago than in Buffalo, while at the Missouri river the total annual rainfall is only about 20 inches, and at the foot of the Rocky Mountains it is often not more than 7 or 8 inches. These figures, then, emphasize the great importance of securing soils having capacity to retain and conduct water.

93. *Kinds of soil water*—The water contained in soil may be considered to be of three kinds, for which the names hydrostatic water, capillary water, and hygroscopic water are generally given.

Hydrostatic water is spoken of by some authors as ground water or standing water, and Whitney speaks of it as gravitation water. Hydrostatic water is that portion of the soil water which stands between its particles, that would drain away if given an opportunity to escape. Below a certain level, which may be at a greater or lesser distance from the surface, in all soils we find the spaces between the particles entirely filled with water. This water which stands between the particles is hydrostatic water. The height to which it rises in the soil is indicated by the level which water reaches in surface wells or holes which are sunk in the field. The upper surface of the body of hydrostatic water is designated the water table.

Capillary water is that part of the soil water which would be retained in

the interspaces of the soil under existing conditions and which would move through the soil from a more moist to a less moist portion, even in opposition to gravitation, which tends to cause it to move downward. Capillary water is often drawn from the hydrostatic water in the lower portion of the soil, climbing up through that portion of the soil between the water table and the surface as oil climbs up through the wick of a lamp. It is the capillary water of the soil from which the roots of plants mainly derive the needed supply.

The hygroscopic water of the soil is that portion of the water found on the surfaces of the particles which is not capable of movement through the action either of gravitation or capillary force. According to some authorities hygroscopic water is that part of the soil water which is absorbed out of the air. Hygroscopic water does not change the appearance of the soil, it does not cause it either to look or feel moist. The amount present is usually small and of no direct importance to vegetation as a source of supply. Hilgard points out, however, that in very hot weather hygroscopic water undoubtedly helps to prevent the soil from becoming excessively hot.

94. *The water capacity of soils* — The capacity of a soil to hold water is always exactly proportional to the total space between all its particles. This varies quite widely in different soils. In coarse sands it amounts to about one-third of the space occupied by the soil ; while in soils rich in vegetable matter it may amount to about two-thirds of the whole. When a soil is fully saturated with water all its interspaces are filled, and accordingly it is found that soils will hold from about one-third to about two-thirds of their volume of water. The plant, however, cannot grow in a soil where the spaces are entirely filled with water. For healthy root development the soil must contain air as well as water. Of greater importance, then, than a knowledge of how much water a soil would hold with its spaces entirely filled, is a knowledge of how much water it retains when there is free opportunity for water to escape by drainage. In other words, it is important to know how much capillary water soils of different kinds contain. The different soils vary widely. The coarsest sands retain but little capillary water, sometimes not more than 15 per cent. ; while the heavy clay loams and soils

containing a large amount of humus retain much more, often amounting to as much as 50 or 60 per cent. Ordinary loams are usually able to hold about 40 per cent. of capillary water. A good loam with a subsoil also of such structure as to favor the retention of water often holds within a depth of five feet from the surface such an amount of water as to equal a layer over tne entire field of from 11 to 20 inches in depth. It is chiefly upon this great store of water and that which rises from below to replace it, when taken up by plants or lost by evaporation, that the growing crop depends for its supply.

95. *Percolation of water*—The passage of water downward through the soil in obedience to gravity is known as percolation. Percolation is always greatest where the capacity to retain water is least. The characteristics in soil which produce little retention are favorable to large percolation, and the opposite is equally true. As a rule water percolates the more rapidly in proportion as the particles making up the soil are coarser. Experiments have shown that only about one-eighth as much water will percolate in a given time through a sand with grains of the average diameter of 1-100 of an inch as will pass in the same time through a sand whose grains have an average diameter of about 2-100 of an inch. The quantity which will pass through a clayey loam is only about one-twentieth as great as the quantity which will pass through the finest sand. If clay be puddled, *i. e.*, worked in any way until it has been reduced to a mass of single particles, practically no water can percolate through it, and, even in the condition in which we ordinarily find clay in the field, the resistance to the passage of water is so great that it percolates only with extreme slowness. The slow percolation through the finer soils is due mainly to the fact that the spaces between the particles are so small that the resistance to the downward movement of the water is very great. If the soil contains a large amount of clay the passage of water is further hindered, because clay often contains considerable jelly-like substance which occupies the interspaces, absorbs considerable water and holds it most retentively. Under conditions existing in fertile loams percolation is much facilitated by the presence of the channels opened by earthworms or by the roots of plants, as well as by the minute crevices

and cracks which form in time of drouth. It is in the case of the clay soils that the last named effect is most important. Both too rapid and too great percolation on the one hand, and, on the other hand, too slow or too little percolation are undesirable: the first, because the water passes too rapidly below the reach of the roots of plants and because soluble plant food is likely to be washed into the subsoil; and the second, because the soil is likely to become too cold and wet and to be imperfectly aerated.

96. *The capillary properties of soils* — Those properties of the soil which affect the amount and the movement of the capillary water are of the utmost importance. They undoubtedly affect its value more than any other characteristic. The word capillary comes from the Latin word which means hair. The movement of liquids upward in obedience to the laws of capillary attraction was first noticed in excessively fine glass tubes open at both ends and standing in water or other fluids, and hence, since the opening of these tubes was hair-like, the name "capillary attraction" was selected. The rise of liquid in the fine tube is not as a matter of fact due to the action of any special force peculiar to the tube. The surface of any solid when plunged into water is wet when withdrawn because the water adheres to the solid. Water rises in a glass tube or in the small spaces existing in a mass of earth simply because of the attraction of the surface particles of the glass or sand for the water. This attraction is at first greater than the attraction of gravitation and the water will continue to rise until it reaches such a height that gravitation balances the attraction of the surfaces. The height to which the water is raised is greater the narrower the tube or the finer the spaces in the soil. In soils we have not, it is true, any system of unbroken tubes, but the various particles rest one upon the other and the spaces between are at many points very narrow and so the water moves in obedience to the same force as in the fine tube. There is in addition another force at work. This is known as surface tension. The film of water which surrounds the particles of soil may be likened to a thin membrane or skin surrounding the particle and exerting a considerable pressure upon it. Surface tension causes this thin film of water to adhere closely to the particle. It should be remembered that every particle of soil under

ordinary conditions is surrounded by such a film of water. Under varying conditions of weather and drainage these films of water which surround the particles come to vary in thickness in different parts of the soil, but whenever two particles holding unequal amounts of water lie in contact with each other there is a tendency to equalization. The particle which holds more water gives up a portion to the particle which holds less. Capillary water in soils, then, is held in part in the small spaces as the water is held in a fine tube, in part as a thin film on the surfaces of all the particles, and there is a constant tendency for this water to move in obedience to the laws of capillary attraction and surface tension until the supply is equal in all parts of the soil. Absolute equality, however, is practically never reached. Gravitation helps to prevent. There is more capillary water near the water table than at a greater distance. As a rule the proportion of capillary water decreases from the part of the soil immediately above the water table, which contains most, toward the surface, which, except soon after or during storms, usually contains least. It should be remembered, however, that water may move downward or sidewise in obedience to the laws of capillary attraction and surface tension as freely as upward ; indeed, more freely, because gravitation does not resist such movement to the same extent. It is, however, the movement of the water from below — from the great reservoir of hydrostatic water found in practically all soils — which is of most importance. All soils possess more or less capillarity. The coarser soils such as sands have least of this property. Water will rise rapidly through sand for a time but the spaces are so large that it is not raised to any considerable distance. In finer soils the water rises more slowly but it continues to rise for a long time and will rise to a considerable distance. The presence of silt and of a moderate proportion of clay is highly favorable to capillary action ; so, too, is the presence of humus, while on the other hand the presence of large proportions of coarse sand and gravel is highly unfavorable. The rise of capillary water from below during the growing season plays an important part in supplying our crops with needed moisture. When the water table is far below the surface, capillary action may not bring it to the very surface, but in almost all cases the movement upward will bring the

water sufficiently near the surface so that the roots of ordinary plants can feed upon it. When a soil contains about one-half of the total capillary water it is capable of retaining, the conditions are usually best for the growth of the crop.

97. *Evaporation of water* — Under ordinary conditions water is steadily evaporating from the surface. The conditions which favor rapid evaporation are high temperature, dry air, and drying winds. The rate at which water is lost as the result of evaporation is affected by the following soil conditions: —

1st. The coarser the soil the more easily it parts with water.

2d. Humus increases the capacity of the soil to hold water.

Sandy soils as a class dry rapidly. Clays and heavy loams hold water very retentively. The amount of water which will evaporate from a given field depends, further, upon the amount of surface exposed to sun and air. A roughly plowed field dries more rapidly than a field which has been harrowed and rolled. The escape of water into the air by evaporation is, from the farmer's point of view, a loss, because his crop is likely to need more water than it finds Whatever can be done, then, to decrease the loss of water by evaporation is in many cases desirable. The escape of water into the air, from another point of view, must be looked upon as more serious than a simple loss of possibly needed moisture. It is more serious because the evaporation of water cools the soil, and, other things being equal, the soil from which a large quantity of water is evaporating must be considerably cooler than one from which evaporation is small. In the case of observations in many different places it has been found that a wet soil from which water is rapidly evaporating is often as much as 8° or 10° cooler than a drier soil of the same characteristics. The evaporation of water from a soil is naturally greater during summer than winter, but even during the latter season when the ground is bare there is sometimes a loss amounting to from 1 to 1½ inches per month. In summer when the weather is very hot and dry and with violent drying winds, the loss of water by evaporation is sometimes as great as 5 inches per month. The total loss of water from the surface of cultivated land as a direct consequence of evaporation seems to amount in some parts

of New England and the Middle States to a layer about 20 inches deep per year. The loss of water by evaporation may to some extent be lessened by frequent shallow cultivation, by wind-breaks, and by mulches. The frequent shallow cultivation of fields and gardens is one of the most effective of the means whereby evaporation can be lessened. A shallow layer of mellow and light soil at the surface prevents in a measure the movement of capillary water to the surface, where, being exposed to the air and the heat of the sun, it is likely to evaporate. This effect appears to be due to the fact that in the mellow soil the spaces between the particles are so large that water cannot move through it freely. Water will rise from below in obedience to the laws of capillary attraction until it reaches this loose and mellow earth. Here it is in a measure stopped. The soil below this layer will remain permanently moist, while the layer itself may be dry. Frequent shallow cultivation in time of drouth is one of the most effective of the means whereby injury from drouth can be prevented. A covering of straw, seaweed, or hay, known as a mulch, acts in somewhat the same way. The soil below the mulch is kept moist, while the mulch itself may be dry. The use of certain fertilizers will sometimes give soil added power to hold water. Among such substances may be mentioned muriate of potash, nitrate of soda, and common salt. An increase in the quantity of humus in the soil is another effective means of helping it to hold water and thus of lessening the loss by evaporation.

98. *The ability of plants to exhaust the soil of water* — No plant is capable of using all the water which the soil contains. When the amount of water falls below a certain limit the plant wilts, although there may still be a considerable amount of water in the soil. This is because the soil holds a small quantity of water so firmly that the root cannot take it. It has been pointed out (94) that some soils hold water in much greater amount than others. Plants will wilt on these soils when they contain a larger proportion of water than suffices for the needs of the plant on a more sandy soil. Sands usually retain only from 15 to 20 per cent. of capillary water. The plant continues to grow until the amount of water is reduced to 5 or 6 per cent. Loams are capable of retaining from 40 to 50 per cent. of capil-

lary water, but plants growing on loams will wither when their water content is reduced as low as 12 or 15 per cent. As a general rule plants begin to wilt as soon as the water content of the soil in which they are growing becomes less than one-third of the total quantity they are capable of holding. On the other hand, few crops thrive when the soil in which they are growing contains much over 60 per cent. of the total quantity a soil can hold.

99. *The effect of drying* — The most noticeable effect produced on soils by drying is a decrease in bulk. The results of this decrease are often seen in the case of clayey soils, which contract to such an extent that narrow cracks open in the soil. Just as the board or plank sometimes cracks or checks on drying, so does the clayey soil crack. This cracking of heavy soils in dry weather is highly injurious to the crops growing upon such soils (75) and the careful cultivator seeks to prevent injury by frequent shallow cultivation. If the surface can be kept loose and mellow by frequent stirring, injury from this cause is prevented. Soils which consist largely of peat or muck, which in their natural condition are usually very wet, shrink a great deal after drainage. This is partly the direct consequence of the loss of water, but is in part due to the decrease caused by the rotting of the vegetable matter which sets in after the water is removed. After thorough drainage the level of marshes falls, and tiles which were originally sufficiently deep are brought too near the surface. In planning for drainage of such soils this point should be kept in mind.

100. *Absorption of vapor of water by soils* — It was formerly believed that under some conditions soils are capable of absorbing a considerable amount of water from moisture-laden air, and that the water so absorbed would prove useful to the growing crop. It is without doubt true that soils sometimes absorb moisture from the air. They do this in obedience to the same laws as those which cause the wood in a chest of drawers to absorb moisture and to swell so that the drawers cannot be moved. The quantity of water, however, which can be thus absorbed by soils appears never to be sufficient to serve as a direct source of moisture to the crop. Long before the soil is sufficiently dry to absorb moisture from the air, the crop must have withered and died. There is, however, air in the soil occupying the

spaces between the particles. These particles are generally moist and the air in contact with these moist particles takes up large amounts of moisture. Under some conditions this moist air rises through the soil and as it comes into contact with drier soil nearer the surface this soil may take up a part of the moisture which the air carries. Hilgard believes that moisture so taken up plays an important part in tempering the heat of the surface soil. He believes that without it soil near the surface might often become far too hot for the best growth of the crop. The absorption of moisture from the air and the evaporation of this moisture from the surface soil helps to prevent this over-heating. The conditions favorable to the absorption of vapor of water from the air are the same as those which give the soil good capillary qualities, viz., fineness, as in soils containing fair amounts of clay and silt, and a large proportion of humus.

XXI — RELATION OF SOIL TO HEAT.

101. *Importance of a suitable temperature in the soil* — The relation of the soil to heat greatly affects its value, and as a rule in the climate of New England and the Middle States the conditions which favor warmth in the soil are to be looked upon as desirable, for the reason that the seasons in this part of the country are comparatively short. Many of our crops are liable to injury from frosts, and anything which increases the heat of the soil, especially in spring or fall, is desirable. Plant life is possible only within certain limits of temperature. Below a certain degree of heat, which is different for different plants, seeds fail to germinate and the plant fails to grow. Wheat, rye, peas, clovers, and turnips will germinate when the soil has a temperature of from 32° to 40° F.; corn, sorghum, carrots, when it has a temperature of from 40° to 51° F.; tomatoes, tobacco, and pumpkins, when the soil temperature is from 51° to 60° F.; while cucumbers and melons will not germinate when the temperature is under 60° F. The *best temperature* for the germination of some of our most common seeds is as follows:—

For barley,	61°-77° F.
For oats,	77° F.

For turnips,	77°-88° F.
For clover,	77°-100° F.
For cucumbers,	88° F.
For corn and melons,	88°-100° F.
For pumpkins,	100° F.

The influence of temperature is not confined to germination. It is equally as great on the later growth of the crop. As a rule those crops whose seeds germinate at a comparatively low temperature will grow and mature in comparatively cool soils. A crop of barley has been grown with the temperature of the soil as low as 50° F. but it was imperfectly matured. Growth was far better at 68° F. Rye will mature at a lower temperature than barley; wheat requires a somewhat higher temperature; and corn higher still. The temperature of the soil, besides directly influencing the germination, growth, and ripening of the crop, influences the supply of available food in the soil. A high temperature is favorable to the decomposition of vegetable matter and humus and helps to convert the nitrogen of such materials into nitrates, which, it will be remembered, are the best nitrogen food constituents (22).

102. *Sources of heat in the soil*—The temperature of the soil is affected to some slight extent by the internal heat of the earth and by chemical changes, especially the rotting of organic matter, but its temperature depends almost entirely upon heat received from the sun.

(*a*) There is no doubt that the interior of our earth is still enormously hot. The excavation of deep mines and wells has shown that when we get below the surface soil the average temperature usually increases about 1° F. in each 50 or 60 feet of depth. To how great an extent the interior heat is conducted to the surface soil has not been determined, but that this heat does affect the temperature near the surface is evident from observations which have been made, as well as from some facts which have come to the attention of almost all. A set of observations made in Pekin are of the greatest interest in this connection. These show the temperature of the soil at different distances below the surface on a number of different dates. The most important results are shown in the table :—

Soil Temperature. Pekin.

Depth. Inches.	March 1.	March 8.	March 15.
18.7	1.43	3.24	4.23
40.0	3.34	4.17	4.93
63.0	5.54	5.83	6.30

It will be noticed that, as would be the case here at the same season, the temperature of the soil at each of the given depths was increasing as the season advanced. It will be further noticed that the temperature of the soil at the middle depth is higher than at the surface at all three dates. The temperature of the earth at this depth therefore could not have been raised by contact with the earth above it. The increase in the temperature of the middle layer, as well as of the lowest layer, must be due to heat rising from below. Nearly every one must have noticed that, especially in seasons when the snow is deep, the frost comes out of the ground from below. It would seem that this also must be due to the interior heat of the earth.

(*b*) *Chemical changes as a source of heat* — Many chemical reactions are accompanied with heat, but the only chemical changes which result in the production of sufficient heat to be of any particular importance in the soil are those connected with the decay of vegetable matter. As much heat will be generated by the slow rotting of a log in the open air as would be produced should the log be burned in a fire. It is equally true that as much heat is produced by the rotting of strawy manure or vegetable matter of any kind as would be produced should these materials be burned. When the soil receives a heavy application of manure which rots rapidly, as, for example, horse manure, its temperature is sometimes appreciably raised. Georgeson found that the average temperature of soil during the first twenty days after manuring was raised about 2.25° F. by the application of 40 tons of manure to the acre. By the application of 80 tons to the acre the average temperature was raised from 3° to 4° F. Wollny observed that an application of 20 tons of manure appreciably raised the temperature of the soil for a period of time varying from four to twelve weeks. The average increase of the temperature of the soil was 1° F. The influence of a heavy application of manure in raising the temperature is sufficiently great to be measured for only a comparatively short time; nevertheless, since seeds

are often put into the ground immediately after manure is applied, this increase in temperature may push the crop forward to such an extent as to be of practical value. The mixture of any kind of vegetable matter with the soil may also result in an increase in its temperature. The plowing in of green crops may have this result ; but such crops rot so much more slowly than stable manures that the increase is much smaller. These crops rot fastest in warm weather ; in the early spring they would not rot with sufficient rapidity to appreciably raise the temperature of the soil. Tillage operations, which loosen the soil and let the air into it more freely, cause a more rapid decay of organic matter and may therefore help to make the soil warmer.

(*c*) *The heat of the sun* — Heat derived from the sun is, of course, the chief means whereby the soil is warmed. It, alone, suffices under favorable conditions to raise the soil to such a temperature that germination of seeds and the growth of crops are possible. In some northern latitudes which are occupied by man the subsoil is always frozen, the crops coming to maturity in the portion of the soil at the surface thawed and warmed by the heat of the sun. The extent to which solar heat warms the soil is modified by numerous conditions.

103. *Color as affecting the temperature of the soil* — That a soil, the surface of which is dark or black, under otherwise equal conditions, is always much warmer during the hours of sunshine than one with a light-colored surface has been pointed out (90).

104. *The specific heat of the soil* — As specific gravity is an indication of weight as compared with water taken as a standard, so the specific heat of soils indicates the amount of heat required to raise their temperature to the same amount as water taken as a standard. The specific heat of water, then, is considered 1, that of ordinary soils is .20 or .25. This means that to raise the temperature of the soil to the same amount as the temperature of water would be raised requires only from 1-5 to 1-4 as much heat. In other words, if both soil and water receive the same supply of heat, 4 or 5 pounds of soil will be raised in temperature to the same degree as 1 pound of water. It therefore follows that the soil which contains much water warms slowly.

Wet soils are cold soils (66). An actual difference of temperature amounting to from 10° to 18° F. has been noticed between soils of the same character, one wet and the other dry. The variation in specific heat of different dry soils is not very wide. Those whose specific heat is least are warmed most by exposure to the sunshine, provided the color is the same. The difference in the specific heat of different volumes of soils of different kinds, provided they are all dry, is not sufficiently great to materially affect the rate at which they warm. It is the amount of water which the soil holds, chiefly, which has an influence on the rate of warming. Soils which retain least water warm most quickly. Sands, therefore, warm more quickly than silts and clays. A soil containing much humus warms comparatively slowly on account of the large amount of water retained. The dark color of the humus, on the other hand, favors absorption of heat. Tillage, which usually makes the soil at the very surface drier, facilitates the warming of the surface soil.

105. *The power of the soil to conduct heat* — The temperature of the soil depends in part on its power to conduct heat. It is the surface soil which is warmed first by the heat of the sun. This heat is gradually conducted downward. The rate at which it is conducted differs widely in the different soils. As a rule the coarser the soil particles the better its conducting power. Gravels and coarse sands, when not disturbed by tillage operations, conduct heat downward best and therefore warm most deeply. Tillage, widening the spaces between the particles of the soil, hinders the passage of heat downward, while rolling helps in that direction. The amount of water in the soil influences the conduction of heat. Water, it is true, is a poor conductor, but poor as it is it is better than air. The more air in the interspaces of the soil the more slowly it warms downward. When water is present in large amount, replacing the air, the soil warms downward more rapidly. A fine, dry, and loose soil conducts heat the worst of all kinds. The gravelly and sandy loams, which not only conduct heat freely but hold it retentively, average warmer than other soils and are therefore always selected for early crops.

106. *The angle at which the sun's rays strike the earth* — The angle at

which the rays of the sun strike the soil influences its temperature in a marked degree. The more nearly perpendicular they are the more they warm the soil. In the latitude of the northern portion of the United States the sun is always in the south, the height in the heavens varying, as is well known, with the season. It follows from this fact that when the surface of a field or garden slopes moderately to the south the rays of the sun are more nearly perpendicular to the surface and the soil becomes warmer. The precise angle which would insure the greatest possible absorption of heat must of course differ with the height of the sun, or, in other words, with the season. It is of course most important that conditions be made as favorable as possible for absorption of heat in spring and fall, and for this reason a slope with an angle of from about 25° to 30° from the horizontal is usually considered best. A slope slightly to the east of south is generally warmer during that part of the year when the extra warmth insured by the slope is most important, but some crops, especially fruits grown on the southeastern slopes, are particularly liable to injury from strong sunshine in the early morning while still frozen. The selection of a southern or southeastern slope is particularly important for vineyards and for early garden crops.

107. *Vertical walls affect the temperature of the soil* — It is a fact of everyday knowledge that it is warmer on the south side of a vertical wall of any kind than in the open air, and very much warmer than on the north side. In some observations which have been made the soil on the south side of a wall at the surface was found to be 32° higher than on the north side, while at a depth of four inches the soil on the south side was 18° the warmer. These observations were made in the month of March. It is in part to secure the advantage of this increase in temperature that lines of board fence are usually put up on the north side of hot beds and early seed beds, and it is because of the superior warmth on the south side of reflecting walls that certain fruits will ripen in some localities in latitudes so far to the north or in so cold a climate that they would not come to maturity without this advantage.

108. *Influence of vegetation* — When a soil is covered by a thick

growth of plants of any kind it is colder in summer and warmer in winter than if bare. A thick growth of grass keeps the soil beneath much cooler than similar soils without such a covering. This result is in part a consequence of the shade afforded by a thick growth of plants of any kind, but is also partly due to the fact that the soil if thickly filled with grass roots is a much poorer conductor than it would be if not so filled.

109. *Influence of water on the temperature of the soil* — A number of important influences which water exerts on the soil have been pointed out (95, 97, 104). The influence of the water in some directions is favorable to warmth, but in other directions its influence is very unfavorable. The final effect of the presence of large amounts of water is to greatly lower the summer temperature of the soil. It has this effect, first, because of the high specific heat of the water, which causes it to warm relatively little in the sun; second, because when it evaporates it renders a large amount of heat latent. King has calculated that the evaporation of one pound of water from a cubic foot of clay will lower the temperature of the clay about 10°. Third, wet soil is a better conductor of heat than dry, and so the heat absorbed by the surface soil is conducted downward to the subsoil to a greater extent in wet than in dry soils. The consequence is that the surface soil is cooled. Water exercises so great an influence on the temperature of the soils that it overbalances all other conditions which are favorable to warmth. A dry soil of a light color is consequently warmer than a moist soil of a dark color. The coldness of soils during the summer season will generally be found almost exactly proportional to the amount of water present. The wetter the soil the colder it usually is. It is only during the winter that the wet soil may be warmer than a dry one. Whenever the subsoil is saturated with water the rise of this water due to capillary attraction tends to keep the surface soil cold.

It sometimes happens that in early spring we have rainfalls which bring water considerably warmer than the soil. When this is the case, if the soil is of such character that the warm rain can soak freely through it, it is sometimes quite rapidly warmed. It is, practically, only under such conditions that the effect of water is favorable to a rise in the temperature of the soil.

110. *The temperature of the subsoil*—In the latitude of the northern part of the United States the temperature of the soil at the surface, especially during the summer, varies widely from day to night, but this daily variation is seldom felt below the depth of about three feet. The variation in temperature due to a change in season is of course felt to a considerably greater depth, but observations show that at the depth of only twenty feet the difference in temperature of the soil from summer to winter usually amounts to only 1° or 2°, while below the depth of seventy-five feet the temperature of the soil is practically unvarying. In temperate climates the temperature of the subsoil at moderate depths is somewhat cooler than the temperature of the surface soil from about the first of April to the first of September, while during the balance of the year the subsoil is somewhat warmer than the surface soil. The temperature of the subsoil at moderate depths is of course affected by the varying temperature of the soil above, and to some extent by the less varying temperature of the soil below. The extent to which the temperature of the subsoil at moderate depths varies depends largely upon the power of the soil to conduct heat.

111. *Comparative temperature of soil and air*—The average temperature of the soil throughout the year is not far from that of the air in the same locality. The surface soil, however, during the hours of bright sunshine not infrequently becomes much warmer than the air, and at night it may sometimes become cooler, although extensive observations by Stockbridge appear to indicate that in most cases the temperature of the soil at the surface even at night is higher than that of the air. In explanation of the fall of dew, soils and plants are often compared to an ice pitcher upon the cold surface of which some of the moisture of the air condenses, and the conclusion is therefore sometimes drawn that soils and plants may gain water during the night in the form of dew. Stockbridge's observations make it evident that the cold air at night must usually play the part of the ice pitcher, and that the moisture contained in the warm air rising from the soil, or being thrown off in the form of vapor from the leaves of plants, is condensed as soon as it reaches the cold open air, and deposited as dew on the surface of the ground or on the leaves of the plant. It would not seem,

therefore, that soils and plants gain water as a rule by condensing moisture from the air in the shape of dew.

112. *The soil air* — The spaces between the particles of soil when not filled with water or when but partly filled with water contain air. This air, however, differs in its composition from the free air above. It generally contains less oxygen, more carbonic acid, and more also of ammonia and vapor of water. The larger quantities of carbonic acid and ammonia are due to the fact that practically all soils contain organic matter or humus and as these materials decay carbonic acid and ammonia are formed. Both of these compounds are gases at ordinary temperatures, but the soil water absorbs them freely and, after being absorbed, they may serve a useful purpose in the nutrition of plants. The carbonic acid absorbed by the water helps it to dissolve plant food (49), while ammonia, absorbed by water and taken in by the roots of plants, is itself a plant food. All soils have a certain amount of ability to absorb and condense gases which may exist in the air, whether it be in the open air which circulates above them or in the soil air. Among gases which may be thus absorbed and condensed the most important, from the standpoint of the farmer, is ammonia or carbonate of ammonia. Observations which have been made in various parts of the world have established the fact that soils absorb a considerable quantity of these compounds — so much, indeed, that it is of distinct benefit to crops. Those soils which contain considerable amounts of silt or organic matter have the greatest capacity to absorb and to hold these compounds.

The oxygen of the soil is not without importance, for seeds cannot germinate nor roots grow in a healthy manner in the absence of this element. In soils which contain insufficient air seeds rot, and first the root and then the whole plant becomes diseased. The oxygen of the soil air, moreover, is one of the most active of the agents which gradually render constituents of the soil available as plant food (48).

113. *The soil and electricity* — Modern investigation indicates that there are frequently weak currents of electricity passing through soil. This electricity is for the most part of frictional origin; the movement of particles of the soil one over the other and the contact of the moving air in the shape

of wind with the surface of the ground generating weak electric currents. So far as is known the electricity of the soil is not of great importance. It has been determined, however, that the passage of electricity through the soil may have a slight effect in making some of its useful constituents more soluble, and it is furthur known that ozone is largely produced by the passage of electrical currents through the air. Ozone is simply what may be termed a condensed and more active form of oxygen, whose action upon the soil may be important in increasing the availability of some of its constituents. It seems quite certain, however, that the amount of electricity in soils under natural conditions is not sufficient to be of any considerable importance. There is some evidence to show that passing moderate electrical currents through the soil may have a sufficient effect upon plant growth to be of practical value. The electricity for such currents has in some cases been collected from the air, and in others has been artificially produced.

114. *Capacity of soils to hold dissolved solids* — All soils have ability to hold larger or smaller amounts of compounds which are brought into contact with them dissolved in water. Thus, for example, if a strong brine or sea water be made to soak through a layer of sand, a considerable part of the salt is taken out and retained by the sand. Still another example is afforded by what takes place in sewage irrigation. The sewage contains a considerable quantity of dissolved impurities, but the water which flows from under drains in fields irrigated with sewage is comparatively pure, the soil having retained a large part of the compounds which were dissolved in the sewage water. This capacity of soils is one of much importance, for without it there must necessarily be great waste of the more soluble and valuable constituents of manures and fertilizers and of those soil constituents which are rendered soluble by the action of natural agencies. This fixation of dissolved substances is due to the action of both physical and chemical forces, and the subject is not to be considered in full in this place (124). The characteristics which are most favorable to the action of the purely physical forces which enable soils to hold dissolved substances are fineness and the presence of large quantities of clay, silt, and

humus. The coarse sands and gravels have comparatively little power to retain soluble compounds.

XXII — CHEMICAL CHARACTERISTICS OF SOILS.

115. *The composition of soils* — Physically considered, soils are composed of finer or coarser particles of rock and organic matter. It has been pointed out that the proportion of the different constituents and their state of pulverization greatly affects the value of soil because of the relation to water and heat as well as to other agencies. We have now to study the chemical composition of soils. In other words, we have to consider the kinds and amounts of the various chemical compounds found in soils and their influence upon fertility. Whatever the source of a soil may be, the most abundant compound found in it is silica. This is doubtless due to the fact that silica is the most indestructible of the common constituents of rocks. Those constituents which are more soluble have in many cases been largely dissolved and washed away. In some cases it is estimated that rocks to the depth of 100 feet have left behind not more than a foot of soil. Besides silica, soils contain a large amount of alumina; and, in practically all cases, also smaller amounts of oxid of iron, lime, magnesia, potash, and soda, with relatively small quantities of phosphoric and other acids. The agricultural value of the soil is of course dependent upon its capacity to produce crops, and this capacity, since plants take most of their food from the soil, is of course influenced by the composition of the soil. It might be supposed from this statement that one could determine by chemical analysis whether or not a soil would be productive. This, however, is not by any means always the case. Fertility depends not simply upon what is present but upon the form in which it is present, as well as upon physical conditions. Methods of chemical analysis are not even yet sufficiently well understood to make it possible, even for the chemist after analyzing a soil, to say in all cases whether or not the soil will be fertile. There are, however, a few general facts bearing upon this subject, a knowledge of which is important.

116. *Constituents of soils essential to plants* — It is now generally admitted that of all the constituents found in soils, water excepted, only the

nitrogen, potash, lime, magnesia, phosphoric acid, iron, and sulfuric acid are absolutely essential. Of these the magnesia, sulfuric acid, and iron are almost always present in sufficient quantities. Lime also is sufficiently abundant in many cases. In considering the composition of soils, then, it is of chief importance to take into account the proportions only of those elements which are likely to be deficient. These are nitrogen, phosphoric acid, potash, and lime.

117. *Classes of soil constituents* — We may divide the constituents of soils into three classes: active, dormant, and mechanical. Of the various compounds which are found in soils, some are soluble in water or in the acid of the roots of the plant, and these constitute the *active* constituents of the soil, or, in other words, the available constituents. The percentage of such constituents even in the richest soils is small. The *dormant* constituents of the soil are those which are soluble neither in water nor in the acid of the roots. These are of much less immediate importance than the active constituents, but they are not altogether unimportant because natural agencies will in course of time render them available. Such constituents make up but a relatively small proportion of soils. Chemists in analyzing soils sometimes attempt to distinguish between the active and dormant constituents, but to separate the two accurately in the present state of chemical knowledge is practically impossible.

The *mechanical* constituents of the soil serve mainly as a means of mechanical support for the plant, and not to any great extent as a source of important food elements either dormant or active. Such constituents make up the bulk of all soils, usually amounting to from 90 to 95 per cent. of the whole. The quartz of sand and the alumina of clay make up the bulk of the mechanical constituents of soils.

118. *Results of chemical analysis* — To illustrate what chemical analysis discloses as to the composition of soils, the results obtained in the laboratory of the Experiment Station at Amherst by the analysis of a few different types of soil are given in the table.

COMPOSITION OF SOILS.

SOIL.	Gneiss Soil, Shutesbury. Per cent.	Hatch Experiment Station, Per cent.	Alluvial, Hadley, Per cent.	Limestone Soil, Pittsfield, Per cent.	Diked Salt Marsh, Marshfield, Per cent.
Coarse materials above .0185 mm.	26.26	1.42	.05	18.03	6.13
Fine earth	73.74	98.58	99.95	81.97	93.87
Analysis of Fine Earth :—					
Insoluble Matter	82.68	80.38	82.42	81.05	72.45
Soluble Silica	1.20	2.41	1.78	.78	1.15
Potash	.13	.33	.22	.25	.24
Soda	.38	.29	.21	.96	.19
Lime	.92	.70	.99	1.58	.68
Magnesia	.19	.26	.93	.34	.72
Manganese Oxid	.06	.06	.07	.07	.05
Iron Oxid	3.79	3.76	5.09	5.39	4.47
Alumina	3.01	6.22	3.15	4.32	5.37
Phosphoric Acid	.20	.31	.32	.29	.24
Sulfuric Acid	.03	.15	.27	.08	.64
Carbonic Acid, Water and Organic Matter	6.89	9.80	3.85	4.92	14.42
Total	99.48	99.80	99.28	100.03	100.62
Humus	1.80	1.72	1.97	.87	6.56
Nitrogen	....	....	....	....	....
Ash	.275	.406	.64	.23	.443
Ash contains :—					
Soluble Phosphoric Acid	.036	.079	.145	.029	.093
Silica	.124	.179	.320	.12	.228

In explanation of the significance of these figures, attention is called to the fact that the insoluble portion of the soil is composed mainly of silica. The mechanical constituents of the soil are comprised in this portion. The figure indicating the insoluble portion it will be noted is much greater than any other in the column showing the percentages of the different chemical compounds. The figures indicating respectively the percentages of potash, lime, and phosphoric acid are, as will be noted, exceedingly small. There is, as a rule, at best only a fraction of one per cent. of either of these constituents present in soluble form, but, although these figures seem so small, it will be found on calculation that the soil of an acre contains as a rule quite large amounts of these compounds. It will be noticed, further, that the percentages of humus in different soils vary quite widely, being

far greater, as would be expected, in the soil of the diked salt marsh than in any of the others. It will be remembered that the amount of humus in a soil greatly affects its value. In proof of the statement that although the figures showing percentages of the important elements seem small the aggregate amount of these elements in the soil is considerable, the results obtained by calculation are given in the table below. This calculation is based upon the supposition that a cubic foot of average earth will weigh about eighty pounds in the case of all the soils which are included, except the Marshfield soil, which is estimated at seventy pounds, this doubtless being considerably lighter on account of the larger proportion of humus (89).

The table shows the amounts of the different most important constituents in the soil of one acre to the depth of one foot.

AMOUNTS OF IMPORTANT CONSTITUENTS IN THE SOIL OF ONE ACRE TO THE DEPTH OF ONE FOOT.

	Nitrogen.	Potash.	Phosphoric Acid.	Lime.	Humus.
Gneiss soil, Shutesbury...........	4,543.35	4,530.24	6,969.60	32,060.16	62,726.40
Hatch Experiment Station.........	6,820.29	11,499.84	10,802.88	24,393.60	59,938.56
Alluvial, Hadley..................	3,845.53	7,666.56	11,161.24	34,499.52	68,751.56
Limestone soil, Pittsfield..........	6,202.24	8,712.00	10,105.92	55,059.84	30,317.76
Diked salt marsh, Marshfield.,.....	15,179.22	7,318.00	7,318.00	10,938.56	228,602.88

119. *Amounts of important plant food constituents removed from soils in crops* — In order to make more evident the significance of the presence in soils of such amounts of the important plant food elements as are shown in the table (118), some figures will now be given showing the amounts of these constituents which are carried away in some of our more important crops. The amount of the crop, shown in the table on which this estimation is based, in every case is much above the average obtained by farmers, but it is not much greater than good farmers often obtain.

THE AMOUNTS OF THE IMPORTANT PLANT FOOD ELEMENTS REMOVED IN CROPS.

	Corn.		Potatoes 300 bu.	Timothy Hay 2.5 tons.	Cabbages 20 tons.	Onions 800 bu.	Oat Fodder Green 12 tons.
	Grain 75 bu.	Stover 3 tons.					
Nitrogen	73.97	62.88	52.74	62.00	92.00	112.36	117.36
Phosphoric acid	29.98	17.28	13.68	17.10	8.00	54.08	31.20
Potash	24.78	82.50	91.80	73.00	136.00	104.00	91.44
Lime..........	.95	37.32	2.70	31.00	8.00	66.56	36.96

Comparison of these figures with the amounts contained in the soils to the depth of a foot shows that the soil contains quantities very much greater than the quantity taken by the largest crops within one foot of the surface. Plants, however, send their roots under favorable conditions to a much greater depth than one foot, and the excess of the food constituents in the soil must therefore be vastly larger than a comparison of the two tables indicates, although of course the percentage of food constituents in the subsoil is generally lower than in the surface portion. The question naturally arises, if the food elements are present in the soil in quantities so very much larger than the crop takes, whether it is necessary and why it is necessary to use manures and fertilizers on such soils in order to secure good crops. Experiment has shown that with the possible exception of the Marshfield soil the application of manure or fertilizer is essential. The soil at the Hatch Experiment Station without manure or fertilizer produced twelve years ago (about the time the analysis was made) about thirty bushels of corn to the acre without manure or fertilizer. At the present time those plots which have been continuously cropped without manure or fertilizer yield only about seven or eight bushels of corn to the acre without manure; while those plots to which moderate applications of manure or fertilizer have been made yield corn at the rate of about seventy-five bushels of shelled grain to the acre. The answer to the first part of our question, then, is evident. The application of manure or fertilizer on such soils is essential to the production of a good crop. The answer to the second part of the question is not so easily given. Why, with plenty of nitrogen, phosphoric acid, and potash in the soil within reach of the roots, a good

crop is not produced without manure may not at first be evident. We may, however, readily see two reasons why this is the case. First, the large amounts of food elements present are scattered throughout the entire mass of the soil, while the roots of the crop come into contact with only a small proportion of the soil particles. They cannot be expected, therefore, to find all the plant food. Second, though the amounts of food elements shown in our table were dissolved by the reagents used by the chemist, it is by no means probable that the entire amounts are present in such forms as to be available to the crop.

120. *Fineness affects the solubility and availability of soil constituents* — Although we cannot understand as yet all the conditions which affect the availability of the different elements of plant food in soils, it is thoroughly established that these constituents are more available in the finer than in the coarse soil particles. In one experiment the finer portion of the soil was divided into five distinct grades: clay, finest silt, fine silt, medium silt, and coarse silt, and the percentage of some of the important elements of plant food in each which was soluble was determined. The results were as follows: —

PERCENTAGE OF PLANT FOOD SOLUBLE IN SOIL PARTICLES OF DIFFERENT SIZES.

	Clay, Per cent.	Finest Silt, Per cent.	Fine Silt, Per cent.	Medium Silt, Per cent.	Coarse Silt, Per cent.
Potash	1.47	0.53	0.29	0.12	....
Phosphoric Acid	0.18	0.11	0.30	0.20	....
Total soluble constituents	75.18	20.52	10.32	5.16	3.48

These figures make it very apparent why, from a chemical point of view as well as from a physical, the presence of a large proportion of fine particles in the soil is desirable.

121. *Percentages of food elements in soils of different grades of fertility* — In order to make it possible the more intelligently to judge from the results of chemical analysis whether a soil is to be regarded as rich or poor in the different elements of plant food, the conclusions of distinguished German authorities will be given.

German authorities agree that if the soil contains less than 0.05 per cent. of either nitrogen or phosphoric acid it may be regarded as poor in these constituents; if it contains from 0.05 per cent. to 0.10 per cent. it is moderately rich; if it contains 0.10 per cent. it is average or normal; if from 0.10 to 0.15 per cent. it is good, and above 0.15 per cent. it is rich in these constituents. The conclusions of the same authorities concerning potash are that a soil with less than 0.05 per cent. of potash is poor in that element; with from 0.05 to 0.15 per cent. it is moderately rich; from 0.15 to 0.25 per cent. it is average or normal; if it contains over 0.25 per cent it is rich in potash. The amount of lime needed to make a soil productive varies with the nature of the soil. Loams and clay soils must contain more lime than sandy soils. German authorities regard a sandy soil with less than 0.05 per cent. of lime as poor in that element; with from 0.05 to 0.10 per cent. it is moderately rich; with from 0.10 to 0.20 per cent. it is average or normal; and they state that over 0.20 per cent. of lime is not often found in sandy soils. In loams those which have less than 0.10 per cent. of lime are poor; with from 0.10 to 0.25 they are moderately rich; with from 0.25 to 0.50 they are average or normal; with from 0.5 to 1.00 per cent they are good, and with over 1.00 per cent. they are rich in lime.

122. *The great importance of lime in soils* — Hilgard, who is one of our best American authorities on soils, points out that, aside from its influence on the physical conditions of the soil, which is often important, lime is also of the very greatest importance in controlling the fertility of the soil. If the amount of lime is adequate, proportionally much smaller percentages of the other food constituents will suffice than would otherwise be the case. It follows, therefore, that, other things being equal, a limestone country is generally a rich country (62*a*). It is, however, unfortunately true that even in limestone countries the soil is sometimes comparatively poor in lime, as this constituent may be extensively washed out of soils under some conditions. Liming land is therefore sometimes beneficial even in the regions where the soil has been derived from limestone. This is most likely to be the case in a hot climate with abundant rainfall. Hilgard finds that in those parts of the United States having a comparatively small rainfall the average

percentage of lime in the soil is 1.6, while in the more rainy parts of the United States the average is 0.11 per cent. Lime, therefore, is present on the average in rather over fourteen times greater quantities in soils of the arid parts of the United States than in the more rainy portions.

123. *The forms in which the different food elements exist in soil.*

(*a*) *Nitrogen* — The element nitrogen exists in practically all soils in at least three distinct forms: first, organic nitrogen, *i. e.*, nitrogen which is a part of some compound derived from a plant or animal; second, in the form of ammonia and compounds of ammonia; and, third, in the form of nitric acid. Only the salts of ammonia and nitric acid are of direct value as plant food, and the salts of nitric acid appear to be much the more valuable of the two.

(*b*) *Phosphoric acid* — The phosphoric acid of the soil exists chiefly in combination with such bases as lime, oxid of iron, and alumina. It is capable of combining with quite different amounts of these bases. When it has taken up all that it is capable of holding it is comparatively insoluble and becomes available only slowly If combined with only one or two equivalents of lime it is soluble in water or in the acid of the roots of the plant, and is available. If combined with three equivalents of lime it is much less available. Phosphoric acid appears to exist also in intimate combination with humus, and in this form also it is highly available.

(*c*) *Potash* — The potash of the soil exists in the form of salts of the different soil acids; much of it is combined with silicic acid and in this form it is comparatively unavailable. When combined with carbonic, sulfuric, or hydrochloric acid, potash is far more soluble and available.

(*d*) The lime found in soils is found chiefly in combination with such acids as silicic and carbonic. In both forms it is moderately soluble and available.

XXIII — THE EXTENT TO WHICH SOILS HOLD DIFFERENT FOOD ELEMENTS BY CHEMICAL FORCES.

124. *Importance of chemical agencies as a means of holding food elements* — In considering the physical characteristics of soils it has been

pointed out (114) that, but for the ability of soils to hold food elements which are soluble when applied in manures or fertilizers or which are rendered soluble, there must be great waste of some of these elements. Important as is the possession of such physical characteristics as are favorable to holding soluble elements of plant food, the action of the chemical agencies is in some cases far more effective and therefore more important. The ability of soils to fix elements of plant food by chemical agencies is, however, very different in the case of the different elements, and with some, as it will be pointed out, chemical agencies are entirely ineffectual. The different elements must, therefore, be considered separately.

125. *Fixation of nitrogen* — The nitrogen which is a part of soils is usually present in three distinct classes of compounds, viz., organic compounds, ammonia and ammonia compounds, and nitrates. The organic compounds of nitrogen are found in the roots and stubble of crops, green manures, farmyard manures, and in fertilizers made from vegetable or animal substances. These compounds are insoluble and, unless they are changed by natural agencies, they will of course be held by the soil. They are a part of the organic matter or the humus of the soil. All organic nitrogen compounds, on the decay of vegetable or animal substances or of humus, are likely to be so modified that the nitrogen enters into combination with hydrogen and forms ammonia, and this ammonia usually combines with carbonic acid. The conditions which are favorable to the formation of ammonia and carbonate of ammonia from organic nitrogen compounds are a warm soil, a moderate degree of moisture, and a mellow condition which is favorable to aëration. During summer weather when the soils are well drained and are kept mellow these changes go on rapidly. Both ammonia and carbonate of ammonia are soluble in water, and if water should percolate through the soil in large quantities and rapidly it will carry these compounds with it, unless the soil has the ability to fix them by chemical agencies. This it practically always can do. The ammonia serves as a base and combines with such acids as silicic acid to form salts, which are comparatively insoluble and which remain in the soil under all ordinary conditions. Agencies are always at work in the soil, however, which tend to modify the

form of combination of the nitrogen still further, and, where the nitrogen of the soil at the beginning of the season is present in the form of organic compounds or in the form of ammonia, a considerable portion of it is likely to undergo changes which result in the formation of nitric acid. This acid will generally combine with some base, such as lime, to form a nitrate. The change of organic nitrogen and ammonia into nitric acid is believed to be caused by the growth in the soil of a class of very minute plants (one of the bacteria) generally spoken of as nitric acid ferments. The conditions which are favorable to the activity of these plants are good drainage, a mellow condition of the soil, with the consequent free circulation of the air, a high temperature, and the presence of some alkaline base, such as lime, with which the nitric acid produced can combine. During summer weather, in well drained soil which is not acid, the changes resulting from the formation of nitrates go rapidly on. The nitrates formed in the soil are soluble in water and are not usually held. They are subject to waste whenever water percolates rapidly through the ground in considerable amounts. A very small amount of nitrate may be held in the fine soils by physical agencies, but in all soils through which water percolates rapidly a loss of nitrates is very likely to occur. Such loss is most likely to take place during that part of the year when there is abundant rainfall or large quantities of melting snow, and when the evaporation of water from the soil is least. When evaporation from the soil is abundant, water moves up from below by capillary attraction and will help to bring from the subsoil nitrates which may have been washed down. The most serious loss of nitrates is likely to take place in the fall, because it is at this season that nitrates which have been forming during the summer are likely to become most abundant, and because, at this season with heavy rainfall and short days, the movement of water in the soil is chiefly downward. Farm economy requires that every effort should be made to prevent this loss, which can be, to a considerable extent, accomplished by keeping the soil always occupied with a growing crop, during summer and fall, in order that the nitrates as fast as they are formed may be taken up and made a part of the plant.

126. *Fixation of phosphoric acid* — The compounds of this acid which

are of most interest to farmers, because they are the compounds occurring in soils, manures, and fertilizers, are its salts, which are known as phosphates. Phosphoric acid combines with a number of different bases and forms several salts with some of them. Thus, for example, phosphoric acid with lime forms three different salts which are of agricultural importance. In one of these salts there is one equivalent of lime, in another two, and in another three. We may call these different phosphates respectively one-lime phosphate, two-lime phosphate, and three-lime phosphate. The first of these is soluble in water. It is this phosphate which is found in all superphosphates. The two-lime phosphate is not soluble in water but is soluble in weak acids, such as the acid of the root of the plant. Both the one and the two-lime phosphates are available. The three-lime phosphate is insoluble either in water or in weak acids and is not available. In the common farmyard manures the phosphoric acid present exists in the three-lime phosphate. It is not, then, subject to waste by leaching. Under natural agencies it may gradually change into the two-lime phosphate, some of the other acids of of the soil stealing from it, as it were, a part of its lime. Many fertilizers, such, for example, as acid phosphate and dissolved boneblack, contain a considerable amount of soluble one-lime phosphate together with smaller amounts it may be of the other two. The one-lime phosphate, being soluble in water, would be washed out of the soil should it remain in that form, but the phosphoric acid in the one-lime form is not fully satisfied ; it will take up more lime or some other base instead of lime if brought under the right conditions. Such conditions it finds in soil, which practically always contains such bases as lime, iron, and alumina. The one-lime phosphate will take up some of one or more of these bases, and, when it has done this, it becomes insoluble in water and is not then liable to be lost by leaching. This change will take place rapidly in most soils and must be considered a very fortunate one, for while insoluble in water the phosphoric acid in these compounds is available to plants, being soluble in the acid of their roots. Under some circumstances a portion of the phosphoric acid of the soil may be made soluble or may remain soluble and be washed out, but under ordinary conditions the amount lost in this way appears to be exceedingly small.

127. *Fixation of potash* — The potash of soils is present for the most part in forms which are not freely soluble in water and it is not likely to be washed out. The potash found in our common manures comes chiefly from the urine and is soluble. Much of the potash in wood ashes also is soluble, while the potash of the various German potash-salts, such as muriate, sulfate, and kainite, is readily soluble. When any of these materials, however, are applied to the soil, changes take place whereby the potash becomes insoluble in water and is therefore fixed by the soil. These changes are generally due to the fact that there is an interchange of acids and bases between the soluble potash-salt and some salt which is found in the soil. The salts which are most commonly useful because they make such an interchange possible are silicates of alumina, lime, and some alkali, such as ammonia or soda. If muriate of potash, which is perfectly soluble in water, is brought into contact with such a silicate, the potash will take the place of a part of the lime, thus becoming itself a portion of the silicate, while the lime combines with the acid contained in the muriate and is washed out of the soil. It must be regarded as highly fortunate for the farmer that this change takes place, because soils generally contain much more lime than potash and it can more easily be supplied. Moreover, if one of these two must be purchased it is far better that it should be the lime, because this is much cheaper than potash. The silicates found in soils which serve this very important purpose are sometimes known by the name of zeolites, and the quantity of zeolites in a soil therefore has an important relation to its fertility. It remains to point out that the potash which is fixed by the zeolites, although not soluble in water, is soluble in the acid of the roots of plants and is therefore available.

128. *Fixation of lime* — Soils cannot hold lime by chemical means as effectually as they hold potash, as has just been pointed out. When we apply muriate of potash, the potash is fixed by the soil, but a corresponding amount of lime is lost. Lime, however, is retained by soils to a greater extent than soda, and if the soil contains zeolites, of which soda is a part, the lime may take the place of the soda just as has been pointed out potash may take the place of lime. On the whole, however, under modern condi-

tions of farming, in which considerable quantities of fertilizers containing soluble potash-salts are used, there is likely to be a considerable loss of lime from the soil.

129. *Fixation of magnesia and soda* — Magnesia can take the place of soda in the zeolites found in the soil. A soluble magnesia-salt is therefore likely to be fixed by soils, because almost all soils contain zeolites in which soda is found. Soda itself, among the different bases, is the one which is most subject to waste under ordinary conditions. Sufficient evidence of this is afforded by the composition of the ocean water, in which common salt (a compound of sodium and hydrochloric acid) is most abundant. This salt, in the course of the ages, has been washed out of the soils into the rivers and streams, and by them carried into the sea.

130. *Sulfuric acid and hydrochloric acid* — These acids, under conditions existing in the soil, are usually combined with bases to form soluble salts. These salts usually remain soluble, and are therefore subject to waste whenever water percolates through soils in considerable quantities.

131. *Important facts concerning fixation* — The chief points brought out by the preceding paragraphs which should be kept in mind are: —

1st. That nitrogen in the form of nitrates is not held by soils, but is subject to waste; and that, whatever the form in which nitrogen exists at the beginning of the season, a considerable part of it is likely to be converted into nitrates before the end of the summer.

2d. Phosphoric acid and potash, even although applied to the soil in soluble forms, are usually fixed by chemical agencies.

3d. Lime is subject to considerable loss.

These facts are of vital importance in determining the proper methods in the selection, use, and application of manures and fertilizers in a correct system of farming.

132. *Soils differ in capacity to fix soluble elements by chemical agencies* — That the extent to which different soils can fix and held soluble elements by physical means varies widely has been pointed out (114). It is equally true that the different soils vary widely in the extent to which chemical agencies enable them to fix elements of plant food. As a rule, it is found

that those soils which contain relatively large proportions of soluble silica and alumina possess such ability in highest degree. This is because those compounds between which and soluble salts exchanges of acids and bases take place are most abundant in the soils containing large quantities of soluble silicates and alumina. These constituents of soils are most abundant in those containing considerable clay, and we find, therefore, that the clayey soils have greatest ability to fix valuable plant food elements by chemical means as well as by physical.

133. *Special conditions affecting the supply of nitrogen in soils:*—

(*a*) *Losses of nitrogen* — Most of the conditions under which nitrogen is likely to be lost from the soil have been pointed out. Culture admitting the air promotes decomposition of the organic compounds of humus, the nitrogen is converted into ammonia, ammonia is converted into nitric acid and nitrates, and nitrates are likely to be washed out of the soil. Whenever a soil is continuously cultivated the quantity of humus originally found in it rapidly decreases, and the nitrogen, which was a part of this humus, is to a considerable extent lost. Snyder has calculated that in fifteen years of continuous wheat culture on the fertile soils of the western prairies there has in some cases been a loss amounting to no less than 35,000 pounds of humus per acre. During these same years the store of nitrogen in the soil he calculates has been depleted by about 4,000 pounds; 750 pounds taken out by the crops, and 3,250 pounds washed out of the soil or lost by some other means. Over four times as much nitrogen has thus been wasted as has been taken by the crop. In addition to the sources of loss already discussed, it remains to point out that under some conditions there may be a loss of nitrogen in the uncombined form. Certain microscopic plants, sometimes found in soils feeding upon nitrogen compounds, liberate the nitrogen in the form of a gas, and this gas escapes into the air. How great the loss from this source may be we do not know, but it is no doubt sometimes considerable, being greatest in soils which are poorly aerated.

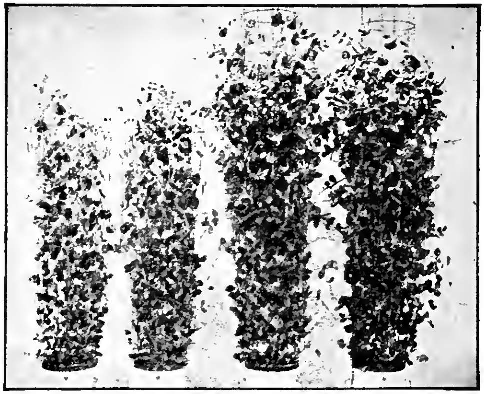
(*b*) *Gain of nitrogen* — In the original rocks which have been broken up to make our soils, there could have been little or no nitrogen. Practically all the nitrogen which is now found in our soils must have come

primarily from the air. It is evident, therefore, that nature has means whereby nitrogen can be so taken. It will be remembered that we have in the air an exhaustless store of nitrogen in the form of a gas (22). It is from this store of nitrogen that the various compounds of this element which have become a part of our soils must have been drawn. Most of the ordinary crops and plants which we see about us, as has been pointed out (22), are unable to make use of this free nitrogen, but there are some humble and apparently insignificant plants which are able to draw their nitrogen from this source. Some of the fungi it is believed have this ability. These plants, having taken nitrogen from the air, contribute in their death and decay to the stock of humus in the soil, and this humus contains nitrogen which, after being converted into ammonia or nitrates, is ready to feed common plants such as grass and the trees which we see about us. The exact facts concerning these fungi are not, however, very well understood, and at the present time the activity of these fungi is probably not of much importance. There is, however, a great family of plants, leguminosæ, a family which contains all the clovers, peas, beans, etc., which has a special and important relation to the store of nitrogen in the soil. The plants of this family live as we may say in partnership with minute plants known as bacteria, and as a result of this partnership the clovers and clover-like plants are able to make use of atmospheric nitrogen. The bacteria which give the clovers and clover-like plants, all of which are sometimes included under the name legumes, this ability to make use of nitrogen drawn

1. 2. 3. 4.

FIG. 6. MANURE USED: 1, None; 2, Nitrate; 3, Potash and Phosphate; 4, Potash, Phosphate, and Nitrate. Oats are much benefited by nitrate alone, but not by potash and phosphate, unless nitrate is used also.

from the air, are found in spherical nodules which develop upon the roots. The size, position, and arrangement of these nodules vary widely in different plants; but however great this variation, the explanation of the presence and of the effect of these nodules is the same in all cases. There is, as has been stated, a partnership between the legume on the one hand, and the bacteria on the other, and, as must be the case in all prosperous partnerships, each partner derives an advantage from the association. The bacteria on the one side are furnished a home or house-rent, a place in which they can live and develop, and in addition they are supplied with starch or sugar as food. Legumes, like all plants which have green leaves, can take in carbonic acid from the air and form starch; the bacteria, having no green leaves of their own, cannot do this. No plant without green leaves can take the carbon it needs from the air. Such plants must always use carbon-containing compounds, such as starch or sugar, which have first been formed by green leaved plants. These, then, are the advantages which the bacteria gains: a home or house-rent and carbon-containing food. The legume, on its side, in return for its hospitality and for a share of the starch it forms, takes a portion of the nitrogen which the bacteria, living in nodules on its roots, are able to draw from the air. The clover, pea, or bean, by itself cannot make any use of atmospheric nitrogen. It is as powerless to do this without the assistance of its little partners as is the corn or potato, but in return for its hospitality and the food it gives the bacteria it gains the enormous advantage of drawing upon the atmospheric nitrogen. Legumes, with the assistance of their little partners, are able to grow and make good crops in soils containing so little nitrogen that crops



1. 2. 3 4.

FIG. 7. MANURE USED: 1, None; 2, Nitrate; 3, Potash and Phosphate; 4, Potash, Phosphate and Nitrate. Peas can take nitrogen from the air. They are not benefited by nitrate alone, and can do as well on potash and phosphate without nitrate as with it.

like corn, potatoes, and timothy, which must take their nitrogen from the soil, would starve. All legumes are very rich in nitrogen; the roots and stubble, leaves and stems, as well as the seeds, contain much more of this element than is commonly found in plants of other families; and the growth of legumes, even when the crop is harvested, is likely to enrich the soil in nitrogen, a large amount of which is left behind in the roots and stubble. To a still greater degree, of course, is it possible to enrich the soil in nitrogen if the legume grown is allowed to remain upon the field. So important is this matter that it is desirable to make clear the conditions upon which enrichment of soils in nitrogen through the agency of this curious partnership depends. The most important points are these: —

FIG. 8. SWEET CLOVER. These two plants grew in the same field; one is without, the other has root nodules. The latter was able to take nitrogen from the air, while the first could not.

1st The kind of bacteria entering into partnership with different legumes is as a rule different for each. The bacteria which can live in partnership with red clover are unable to live on the roots of peas; those which can live in the nodules on the roots of peas are unable to live on beans; and so throughout the entire family. Each of the different legumes must have its own species of bacteria, with possibly a few exceptions in the case of legumes which are nearly alike. These bacteria come from seed just

as truly as does a crop of corn or potatoes or clover, and unless the seed of the right kind of bacteria is present in the soil or is added to the soil when the legume is sown the roots of the legume will remain smooth, no nodules are formed, no bacteria are developed, and the legume must take all the nitrogen it needs from the soil. It is no better as a means of enriching the soil in nitrogen than a crop of any other family. Fortunately, however, bacteria are so minute that the spores or germs (in one sense the seed) from which they come are distributed in countless ways. They are wafted through the air by the lightest breeze, they are likely to be present in the dust adhering to the seed of the legume upon which a given bacterium has grown; they remain in the soil from year to year. When we first begin to cultivate a legume in a given locality, let us suppose it is a new crop like the cow pea or the soy bean, we may find but few of the nodules upon the roots because the right kind of bacterium is not abundant; but this bacterium multiplies rapidly and after a few years is likely to become so abundant that the new crop will thrive much better than at first. In some cases, however, it may become necessary to obtain some of the right sort of bacteria for a new crop, by securing soil from the field where the crop has long been cultivated, or the seed may be obtained in the form of a special preparation which may be called the farmer's legume yeast-cake. This material, which is known by the name of Nitragin, is prepared in some foreign laboratories and is sometimes imported. As a rule, however, it appears to be the case that some of the right sort of bacteria will be found in the dust adhering to the seed of the new crop, and accordingly we have as a rule to wait only a few years before the right bacteria become sufficiently abundant to enable the new legume to derive needed nitrogen from the air. It appears to be true that in the case of all the better known plants of this family, like the common clovers, peas, and beans, the right kinds of bacteria are sufficiently abundant and the farmer needs not to take any special steps to secure them. As is the case with other seeds, so the spores or germs of the bacteria which live in partnership with legumes require certain conditions for their development. The soil must be well drained, mellow so that the air can circulate through it, and warm. It must also be free from uncombined

acids. It is best that there should be a moderate excess of some alkali such as lime.

It is necessary also to call attention to the fact that if legumes can find the nitrogen they need in the soil in the form of such compounds as nitric acid, they will take it from the soil and will not apparently take the trouble to use the nitrogen which may be placed within their reach by their little partners. If, then, nitrogen is to be drawn from the air by the cultivation of legumes, these plants must be sown upon soils which contain only small amounts of nitrogen in combined form, such as ammonia and nitrates. If clover be grown as a green manure upon soil where there is a large amount of assimilable nitrogen compounds, that soil will not be materially enriched as a result. The clover will take out of the soil the nitrogen which it needs and will leave behind, therefore, only what it first found there. In order to derive the utmost benefit from the cultivation of a legume as a green manure it must be planted upon soil poor in nitrogen. It is then forced to live upon the nitrogen brought within its reach by the bacteria living in the nodules on its roots.

It is further important to point out that legumes make use of nitrogen brought within their reach by their little partners chiefly in the later stages of their growth. If one of these crops be turned in before the period of blossoming, it will not have drawn much nitrogen from the air.

134. *The natural strength of soils* — The term natural strength of soils is used to indicate the permanent capacity of the soil to produce crops. It is in proportion to the power which the soil possesses of gradually forming active and available compounds of plant food. Soils differ widely in natural strength, this difference being due largely to the nature of the rock materials comprising them. Experiments at the celebrated Experiment Station at Rothamstead, England, which have been continued for nearly sixty years, during all of which time certain plots have been kept permanently in wheat without the addition of any manure or fertilizer, indicate that the natural strength of that soil is sufficient to render available sufficient plant food to produce an average crop of about 12 bushels of wheat per acre. The soil at Rothamstead must be regarded as one of great natural strength. The

average wheat crop of the United States is not usually any greater than the average yearly product of this Rothamstead soil which has been cultivated nearly sixty years without manure, and it must be remembered that many of our wheat growers use manures and that others have the advantage of soils which are comparatively new and rich. The natural strength of most soils must fall considerably below that of the Rothamstead soil. It should be pointed out, however, that the natural or average productive capacity, whether without or with manures, is influenced by climate and by tillage, as well as by the nature of the constituents which make up the soil, and the climate of Rothamstead is naturally more favorable for the production of wheat than is the climate in most parts of the United States, while the tillage upon these experimental plots has been very thorough; whereas among our farmers it is often quite the reverse. Another illustration giving an indication of what is probably about the natural strength of the soil is afforded by certain plots on the grounds of the Massachusetts Experiment Station at Amherst, where, after twelve years without manure or fertilizer, the average product of corn amounts to about 7 bushels per acre. Experiments on the light sandy soils near the seashore have given crops of not more than from 3 to 5 bushels per acre even the first year without manure or fertilizers, and the natural strength of these soils is doubtless far below that of the Amherst soil. It must be evident that a soil of great natural strength is likely to give far more profitable results in agriculture than one of the opposite characteristics. The moderately heavy or clayey soils, especially in regions where limestone has contributed a portion of the materials of the soil, are likely to possess a high degree of natural strength, while quartz sands possess these characteristics in very low degree.

135. *Soil exhaustion* — Soil is commonly spoken of as exhausted when it no longer produces profitable crops. There is practically no such thing as absolute exhaustion. Even our most worthless soil with a favoring season will produce something. Soil exhaustion is due to the gradual depletion of the store of available food. This depletion may affect all the elements of food which plants commonly take from the soil, in which case exhaustion may be said to be complete, or it may affect only one or a few

of these elements, in which case exhaustion is said to be partial or one-sided: as, for example, if a soil is very deficient in nitrogen, potash, phosphoric acid, and all the other mineral elements, it must be called completely exhausted. If it should be deficient, on the other hand, only in potash its exhaustion is one-sided. One-sided exhaustion can evidently be corrected by supplying the one or the few plant food constituents which are deficient, while complete exhaustion, requiring the supply of all the plant food elements, would render restoration to fertility more difficult and expensive.

136. *Movements of salts in the soil* — The water in the soil always contains salts in solution. Their percentages may be small, but their importance is great because it is these salts which under ordinary conditions comprise the most available portion of the plant food of the soil. The amount of salts in solution in the soil water is variable. The growth of crops and leaching tend to reduce it. Rain brings to the soil a small amount of certain salts, and the decay of vegetable matters and the gradual solution of some of the finer constituents of the soil supply still other salts. The movements of these salts throughout the soil are of much interest and importance in their relations to the nutrition of plants. These movements are due to two causes: —

First, the salts, a part of which remain in solution permanently, move through the soil with the water. When the movement of the water is downward they go with it; when the water moves upward by capillary attraction salts tend to come back with it. Heavy rains furnishing a large amount of water within a short time carry relatively large quantities into the subsoil; and if the nature of the subsoil is such as to promote the escape of this water, or if there are open drains, there may be a considerable loss of soluble salts. If, however, the water which has moved towards the subsoil does not escape, it tends to move back toward the surface when the weather clears and evaporation becomes abundant. The salts which are most likely to be formed and to be moved with the soil water in the manner indicated are carbonate of lime and nitrate of lime. The first will be formed even at a considerable distance from the surface, but the latter is formed almost exclusively in the surface soil. It sometimes happens when the quantity of

salts in the soil is large that after long-continued hot, dry weather we find the particles of the soil at the surface covered with a deposit which looks not unlike hoarfrost. This will be found to consist of salts which have been brought to the surface by the water and which have been left behind as the water has evaporated into the air.

The second agency whereby salts are moved throughout the soil is by diffusion. Diffusion is that property in obedience to which a gas or a salt in solution tends to spread until it becomes equally distributed throughout the air, in the case of a gas; or throughout the fluid in which it is dissolved, in the case of a salt. If, for example, the stopper be removed from a bottle containing ammonia gas, that gas immediately begins to diffuse. Its odor can soon be recognized in any part of a room. In the course of a little time no more of the gas will remain in the bottle than in the air of the room, and in the course of still further time the gas will have found its way out through the cracks around windows and doors into the outer air. It is now no more abundant in the air of the room than outside. The gas has become so widely diffused that its odor can no longer be recognized. In a similar way a dissolved substance diffuses throughout the fluid in which it is dissolved. We may have, for instance, a strong brine in the bottom of a vessel; we may add water with great care not to disturb the fluid and we shall have at the start a strong brine at the bottom and pure water above. The salt, however, although heavier than water will not remain at the bottom, it will begin to diffuse throughout the entire body of water, and in course of time it will become nearly evenly distributed throughout the entire body. In just the same way salts diffuse through the water of the soil. They do this throughout even that part of the water which is held by capillary attraction. If there is a salt dissolved in the water which is held by one particle that is not found in the water held by a neighboring particle, this salt will begin to diffuse into the water of the latter, and through that a part of it will move into the water held by the next, and so on indefinitely. It is equally true that if the water held by the attractive force of one particle contains more of a given salt than the water of its neighbor, a portion of that salt will diffuse. This diffusion will always continue until the salt is

everywhere equally distributed throughout the soil water, or at least this is the tendency, although of course it may very well be that this condition is practically never reached. Soluble salts in the soil, then, have a constant tendency to move from those parts of the soil in which there is more towards those portions in which there is less of the given salt. We apply, let us say, a soluble salt such as nitrate of soda at the surface. This salt may be dissolved in a very small quantity of water and as soon as it is dissolved it begins to spread by the laws of diffusion throughout the entire mass of moist soil. In this way a portion of nitrate of soda is finally brought into contact perhaps with every particle of the soil and wherever the roots spread they find some of this important food. The form of phosphoric acid found in superphosphates, and the potash salts, so often applied, obey similar laws ; and diffusion therefore is undoubtedly the most important and the most perfect means whereby plant foods are distributed throughout the entire mass of the soil. Different salts diffuse with quite different degrees of rapidity. The chlorids and muriates diffuse more rapidly than sulfates. It therefore follows that it may be useful to apply sulfate of potash longer before the crop will need it than is necessary in the case of the muriate, for the sulfate must have considerable time before it will become diffused throughout the soil and it is not until it is widely diffused that it is in the right position to help the crop. Nitrate of soda and sulfate of ammonia diffuse rapidly and this is one of the reasons why it is not essential to apply these long before the crop will need them. The rate at which any given salt will diffuse is affected somewhat by the temperature of the soil. When the soil is warm all salts diffuse more rapidly than when it is cold. In this connection it should be remembered that as soon as the salt, through the action of chemical agencies, is rendered insoluble it ceases to move throughout the soil by either direct movement of the water or diffusion. Potash, for example, applied in the form of muriate diffuses as long as it remains a part of this compound, but when as a result of the changes which have been described (127) it has become a part of the compound silicates of the soil, being no longer soluble, it ceases to move with the water or through the water by diffusion.

XXIV — IMPROVEMENT OF SOILS.

137. *From what has preceded it must be evident that but few soils are perfect* — Practically all the soils in those sections of a country which have been long cultivated are susceptible of improvement. The needed improvement may be either physical or chemical, *i. e.*, it may affect the texture of the soil, and therefore its relations to water, heat, etc., or it may affect the chemical qualities of the soil, *i. e.*, its composition or the nature of the chemical changes which go on in it. It is doubtless true that whatever affects the physical qualities of the soil does usually also affect its composition, especially the proportion of its constituents that are soluble and available to plants ; and it is equally true that the application of materials which affect the chemical nature of soil also often affects its physical characteristics. Still, a division of the general subject of soil improvement under the two heads — physical means of soil improvement, and chemical means of soil improvement — is useful. Under the former we have to consider such operations as mixing soils, and drainage ; under the latter, the discussion of manures and fertilizers and their use is the most important topic.

138. *Operations having for their chief object improvement in the physical condition of soils* — The importance of a right physical condition of the soil as affecting production has been discussed at length. There are several methods of effecting improvement in physical conditions which are of sufficient importance to require special study. These are paring and burning, mixing soils, tillage, and drainage.

139. *Paring and burning* — The operation of paring and burning consists in turning up a shallow layer of the surface soil, including stubble and roots, allowing it to dry for a time, and then burning it ; the organic matter it contains, *i. e.*, the stubble, roots, and humus, serving as the fuel. Special plows have been devised for cutting a shallow slice from the surface and turning it on edge, thus leaving it in good position for drying ; although in some old countries, where land for agricultural purposes is held at a high price, the paring has sometimes been done by hand, the sods being thrown into windrows or small piles to dry. This operation is most useful on clayey

soils and soils which contain a large amount of organic matter. It makes clay soils more friable and renders their constituents to a larger degree available as plant food. The burning of course destroys the organic matter and the humus. There remain only the ashes. The nitrogen which was contained in organic matter and humus is driven off into the air and lost. In some soils this would be a serious matter. Unless, therefore, the resulting advantages are considerable, burning such soils must be considered a wasteful process. In the case of peaty soils there is so large a stock of humus that the loss of a portion of the nitrogen which it contains cannot be regarded as very serious. The burning may be made a means of clearing the surface of brush, coarse grasses, sedges, and rushes, and of refractory vegetable matter which would be slow to rot. The marsh having been cleared of these obstacles to cultivation, it can be put into a valuable crop in a much shorter time after its improvement is undertaken than would be possible without burning. In such cases, however, care must be taken not to allow the fire to burn too deep. This it would do should the water in the marsh stand at too low a level, and the consequence of such deep burning would be a great injury to the soil. Stiff clay soils may be much improved in physical characteristics by burning. On these we do not always find sufficient vegetable matter to serve as fuel. In such cases fuel which is brought to the field is sometimes used. This may be brush or cheap wood, or coal, whichever costs least being selected. The chief benefit resulting from the burning of clays is the change in physical character. It destroys the adhesive tendency of the soil to some extent. The particles which are strongly heated behave thereafter not so much like clay as like fine particles of sand. The soil therefore becomes more permeable both to air and water, and can be much more easily worked. The price of farm lands in most parts of the United States is not, however, usually sufficiently high to make it profitable to undertake this somewhat expensive method of improvement. The modern tendency is to depend rather upon thorough drainage and application of lime to secure the improvement of soils which in earlier years were frequently burned.

XXV — THE MIXTURE OF SOILS.

140. *Possible necessity for the mixture of soils* — It has been pointed out that we have a soil of the best type when we have what may be called a happy mixture of the different constituents clay, silt, sand, and humus (63). If either of these constituents is present in relatively small amounts or is absent, the soil will be of inferior value. As a matter of fact we seldom find a soil which does not contain all four of these constituents, but we do often find soils in which one of these constituents is present in too small amounts to give the best results. In such cases the soil may be improved by incorporating with it a larger or smaller quantity of the constituent which is relatively deficient. Whether or not this operation will be economically advisable or profitable depends upon conditions, and that it will be profitable is by no means always the case. The soils which are susceptible of improvement in the manner now under consideration may be divided into three classes, viz., those deficient respectively in sand, in clay, and in organic matter or humus.

141. *Soils deficient in sand* — There are two leading types of soils which may be improved by the addition of sand, viz., clay soils and peaty soils. Nothing at first thought would seem more certain than that the mixture of sand with clay or peaty soils would give these soils the very qualities which they need to make them valuable in agriculture. The clay is too cold, too impervious to air and water. Sand would raise its temperature and bring it into better relations both with air and water. Peaty or mucky soils lack body; they are subject to too great extremes of temperature; they become hot by day and cool rapidly by night. Sand would correct these difficulties. Notwithstanding these facts, however, practical experience has shown that the application of sand to such soils is not often profitable. Their improvement by this means is practicable only in exceptional cases. The chief reason appears to be the cost, which is due to the fact that a very large amount of sand is required to produce any material benefit. The application of moderate amounts does not produce permanent results. Clay, which appears at first to produce crops much better in quality as a result of the application of a thin coating of sand, in a few years reverts to its original

condition, the sand appearing to be swallowed up in the clay. It will be remembered that sand is the heaviest of all soils. Its transportation any considerable distance, therefore, is costly. Where farm lands are of high value, however, and a bank from which sand can be taken is close at hand, this method of improvement may give satisfactory results. As a rule, however, both clays and the peaty or mucky soils are more profitably improved by thorough drainage, careful tillage, and the use of lime. It should be pointed out that what has been said has no reference to the operation of sanding a bog in preparation for cranberries. This is something entirely different. The value of a productive cranberry bog is so great that the carrying on of three or four inches of sand which is spread upon the surface is usually amply repaid. This sand, however, is not mixed with the soil of the bog.

142. *Soils deficient in clay* — Both soils which contain too large a proportion of sand and those which are peaty or mucky are improved by the application of clay. Practical experience indicates that the improvement of these soils by carrying on clay is far more practicable than sanding. It takes far less clay to improve a sandy soil than it takes of sand to improve one which is too clayey. From forty to sixty loads per acre of clay applied to a light, sandy soil will result in much improvement and this improvement will be quite permanent. It often happens that a bank or bed from which clay can be taken is found not far distant from a light, sandy soil, and it is only necessary to combine the two during the least busy season to greatly improve the light soil. The improvement of peat and muck soils by the addition of clay is not equally practicable.

143. *Soils deficient in organic matter* — The soils which are susceptible of improvement through the addition of organic matter may be of either a clayey or sandy type. Organic matter or humus may be supplied to such soils either by the application of peat or muck or by the growth and turning under of a crop, *i. e.*, by green manuring. The choice between these two methods of improvement will depend upon the relative cost of the two. Where peat or muck of suitable character can be conveniently obtained and the distance which they must be hauled is short, their use in the manner

under discussion is sometimes preferable. The benefit derived from the application of these materials does not consist solely in the physical improvement which addition of humus produces. Peat and muck are manures and often contain considerable quantities of plant food, especially of nitrogen. Their use is elsewhere fully considered (320, 321, 322, 323, 324). When removed from the marsh these materials hold a large amount of water and often contain free acids. They should accordingly be thrown into piles, allowed to drain and to dry by exposure to the air, while at the same time the acids which might be injurious are gradually rendered harmless. After drying and partially rotting, peat or muck may be applied to such soils as need them. The best season is usually autumn. Their application to sandy soils increases the capacity of such soils for holding water and lessens the probability of loss of plant food through leaching. Their application to clayey soils renders such soils less tenacious and more easily worked. In the majority of cases it is believed that the enrichment of soils naturally deficient in organic matter and humus can be more cheaply effected by green manuring, a subject which will be considered in connection with the general subject of manures and fertilizers.

XXVI — TILLAGE.

144. *Definition and objects* — Tillage is the operation of stirring, breaking up, and pulverizing land by means of plows, harrows, or other implements, either before or after sowing the seed. Tillage may be almost indefinitely varied, but there are a few rather distinct classes of tillage which must be distinguished. The term surface tillage is self-explanatory. It refers to the more shallow tillage operations carried out by the use of harrows, some types of cultivators, and weeders. Sub-tillage designates that class of tillage operations which work below the ordinary depth of plowing, such as subsoiling. Inter-tillage designates those tillage operations which are carried out while the soil is occupied by a crop. This may be shallow or deep. It is commonly the former and is carried out by such implements as weeders and cultivators. The word tilth has reference to the condition or degree of pulverization or fineness, the degree of compactness,

etc., of the soil. The soil is said to be in good tilth when it has been loosened and fined to a considerable depth. Good tilth is one of the most important of the conditions essential to success in crop production. Insufficient or faulty tillage is the cause of many failures. If the seed be put in with a soil in poor tilth a good crop is impossible, for nothing which can be subsequently done will entirely correct the faulty conditions. The chief objects of tillage are to break up, mellow, and fine the soil so that seeds may be well covered and roots find their way easily and freely through the soil, to increase the supply of available plant food, to help control the supply of soil water, and to kill weeds. In deciding upon the time and kind of tillage needed, one should be governed by the character of the soil and the needs of the plant.

145. *Tillage in its relations to available plant food* — Tillage has been called the universal manure and its value as a factor in increasing the available plant food in a soil has long been known by both scientists and practical farmers. It was formerly believed that plants fed upon the very fine particles of the soil; and Tull, who lived about two hundred years ago, believed that he proved that this was the case by the very successful results which followed his very thorough tillage. He succeeded in raising better crops without manures with the most thorough possible tillage than his neighbors raised with manures and less thorough tillage. We now know that the roots of plants do not feed upon the particles of the soil, however fine, but scientific investigation has abundantly proved that Tull's conclusion that tillage increases productiveness was correct. There exists in most of our soils (118) enormous amounts of the elements of plant food. The availability of these elements is much increased by tillage. This increase in the availability of the food constituents of the soil is due to the action of both mechanical and chemical agencies.

(*a*) *Mechanical effects of tillage* — First, by fining the soil a much larger soil surface is exposed for the feeding roots to use. Second, tillage constitutes the means whereby the surface soil may be brought into the right degree of compactness for the crop to be raised and kept in that condition throughout the growing season. Some soils in their natural condition are

too loose and open for certain crops. These need a system of tillage which tends to compact the surface soil. They may be benefited by rolling. A larger proportion of our soils, however, are apt to be too compact, and they need a system of tillage which will lighten them and keep them loose and friable. A farmer should closely study the peculiarities of his soil and the conditions of his fields at different times, as well as the special needs of the different crops, and should then apply the system of tillage suited to these conditions.

(*b*) *Chemical effects of tillage* — The chief reasons why tillage has a tendency to increase the availability of the plant food elements and compounds found in the soil are as follows: First, tillage changes the arrangement of the soil and may thus often bring into contact particles which have not before come together. This may cause chemical changes, as, for example, the interchange of acids and bases (127), as a result of which some constituent of the soil is rendered more soluble. Tillage also changes the relations of the soil to the air, the water, the salts, and the gases; and, as a consequence of these changes, chemical reactions often follow which make elements of plant food more available. Perhaps the most important among the factors named is the better aeration which is a consequence of the breaking up and loosening of the soil. The beneficial effects which follow fuller exposure to the oxygen of the air are often important. One of the most important of these is the increased formation of carbonic acid which follows the more complete rotting of the organic matter of the soil caused by better aeration. This increased amount of carbonic acid dissolved in the water of the soil acts as a vigorous solvent on many soil compounds. Among such compounds may be named three-lime and two-lime phosphates and phosphate of iron. Carbonic acid steals a part of the lime or the iron from the phosphoric acid and this as a result becomes more soluble (126). On the other hand, insufficient aeration may result in the formation of compounds which are actually harmful to plant growth, such, for example, as sulfides of iron and sulfate of the lower oxid of iron. Tillage also affects the microscopic plants of the soil, most important among which in this connection may be mentioned the bacteria which cause the loss of nitrogen in

the free form (125) and called the denitrifying ferment, and the nitric acid ferment. The first of these, which is harmful, flourishes where the soil is poorly aerated. The nitric acid ferment, on the other hand, flourishes in soils which are well aerated, and it will be remembered that the result of its activity is to convert the various nitrogen compounds of the soil into nitrates, which are the most available form in which nitrogen can be offered to plants (123 *a*). We see, then, that neglect of tillage may mean the loss of nitrogen, the most valuable soil constituent (133 *a*), while proper tillage, promoting aeration, brings the nitrogen of the soil within reach of the growing crop.

146. *Relations of tillage to water* — It has been found that making the soil more mellow increases its ability to hold water which comes to it in the shape of rain and melting snows. This may be especially important in the case of the more compact soils. If such soils are fall-plowed they absorb and hold a larger amount of the water which comes from winter rains and snows. This is partly because less runs off over the surface, but is largely due to the fact that as tillage increases the amount of the spaces between the particles of the soil more water can be retained. Deep tillage which breaks up a compact layer in the soil may, on the other hand, make it possible for water to percolate downward to a greater extent. This, however, would not generally mean that the surface soil would retain less water, because almost all fields have sufficient slope so that if water is not absorbed it runs off. Under some circumstances, tillage may temporarily decrease the amount of water in that portion of the soil which is stirred and loosened. This would be the case for a time with that part of the soil loosened in hot, dry weather. The decrease in water in this case would be mainly due to the fact that the capillary connection between that part of the soil which is broken up and the soil beneath is disturbed, so that water cannot rise as freely from below. After a time, longer or shorter according to the soil and the weather, soil which has been loosened by tillage settles back into close connection with the part which has been undisturbed and this effect ceases to be marked. Very shallow tillage of growing crops at frequent intervals has, however, been found to be the best method of conserving capillary water during

drouth. Such tillage with implements which stir the soil to a depth of only an inch or two is now almost universally practiced on such crops as corn, potatoes, etc. (97). The use of the different implements of tillage produces varying effects upon the soil moisture. Experiments at the Wisconsin Experiment Station led to the following conclusions :—

1st. Disc harrows and curved tooth harrows, which cut comparatively deep into the soil and leave undisturbed ridges beneath, tend to dry the ground rapidly. This appears to be due to the fact that the water continues to rise by capillary attraction through the soil in the undisturbed ridges which reach the surface of the ground, and this water therefore largely evaporates.

2d. Plows and such varieties of cultivators as cut the whole surface of the ground make the surface soil drier for a time, provided the weather is hot and dry. These implements keep the undisturbed soil below moist. This effect, it will be evident, is due to the breaking of the capillary connection between the soil stirred by these implements and the soil beneath.

3d. Shallow plowing tends to raise the water-table and prevent evaporation. By this statement, it will be understood, it is not the intention to convey the idea that the water in the soil is directly raised by shallow plowing, but simply that, since shallow plowing forms a mulch at the top and prevents evaporation of water, the result is that the water level in the soil is higher than it would be were the soil not plowed.

4th. Fall plowing and early spring treatment with tools like the disc harrow tend to draw water to the surface, and with it come salts which are held in solution. These salts are thus brought into a more favorable position for the crop to feed upon them, and being brought toward the surface they are less likely to be lost by leaching. The greater extent to which water comes to the surface as a result of fall plowing is clearly because of the better capillary connection with the lower soil, which is a consequence of the long time during which the loosened soil has settled more nearly into its original position.

147. *The destruction of weeds* — Inter-tillage is the name which is used to designate tillage given while the land is occupied with the crop. The

destruction of weeds is in many minds the chief object of inter-tillage. Weeds are voracious eaters and "hard drinkers." The folly of allowing weeds to grow and the crop to struggle with the weeds is well known. The injury which the weeds do the crop is indicated by the above statement concerning them. They rob it both of food and water. The loss of the water consumed by the weeds is in most cases more serious than the loss of elements of plant food. Frequent shallow tillage, which should begin before the weeds have fairly vegetated and be repeated as often as they are just about to break the ground, will not only keep down the weeds and thus prevent the very serious waste of water which they occasion, and the less serious waste of food, but will help to conserve the moisture of the soil, as has just been pointed out.

XXVII — TILLAGE IMPLEMENTS AND OPERATIONS.

148. *Classes of tillage implements* — The various implements used in tillage will be included under the following classes : plows, harrows, rollers and clod-crushers, cultivators, weeders, and hand implements.

149. *Classes of plows* — All plows which are used in tillage operations may be included under three classes : the subsoil plows, trench plows, and ordinary plows.

150. *Subsoil plows and plowing* —.

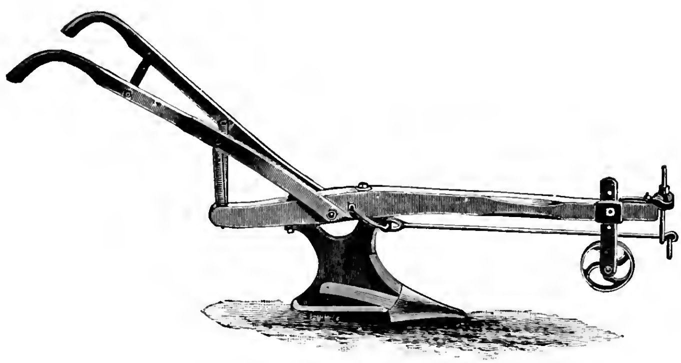


FIG. 9. SUBSOIL PLOW.

The cut shows a subsoil plow adapted to working to a moderate depth. Where greater depth is desired a different type of plow is needed.

Subsoil tillage consists in breaking and fining the subsoil without bringing it to the surface. It is not always either advisable or profitable, but is sometimes useful. It is most likely to prove useful in well-drained soils where the subsoil is hard and dry. It cannot be recommended for wet lands and if attempted where the subsoil is wet and clayey there is a tendency to puddling the clay, which does more harm than good. When, however, there is adequate under-drainage, natural or artificial, breaking up, mellowing, and loosening the subsoil proves useful because it enables the water to percolate through the soil more freely, it results in better aeration of the subsoil, and deepens that portion of the soil in which roots can healthily develop. Roots follow the line of least resistance and if the subsoil is mellow the roots will grow lower than they otherwise would. If the soil be mellow to the full depth required by such crops as carrots, beets, and parsnips they will develop well-shaped, symmetrical, and smooth roots, but if the subsoil be hard the roots will be stunted and deformed. Subsoiling is most likely to prove useful for root crops and for fruit trees. Subsoiling is performed by means of a plow specially designed for the purpose. In subsoiling two teams are required in order to carry on the work to advantage. The first team is for the ordinary plow, the second for the subsoil plow, which is used in the furrow behind the common plow. The power required for the subsoil plow of course varies widely with the soil and the depth at which the plow is worked. It may not be greater than that required for the common plow but it is sometimes four times as much, in which case four or more horses may be needed.

151. *Trench plows* — The trench plow is a type of plow designed for bringing to the surface the soil from considerable depth. It ordinarily follows in the furrow opened by the common plow and raises the earth from the bottom of that furrow and leaves it at the surface. By trench plowing the surface soil may be covered to considerable depth and of course under ordinary conditions this is undesirable. The trench plow has sometimes been used in intensive gardening in the preparation of soil for asparagus,

large quantities of manure being incorporated with the soil to a considerable depth. This operation, however, can seldom be called for, and trench plows cannot be looked upon as of present importance.

XXVIII. ORDINARY PLOWS AND PLOWING.

152. *The parts of the plow* — There is at the present time almost infinite variety in plows, which differ from each other, according to the purpose for which they are made, in the style of construction of almost every single part. It will be impossible to consider all the different styles of plows, but a few points in reference to the special use and the variations in each of the different parts must be brought out. The parts which will be made special subjects of consideration are the beam, the moldboard, the coulter, the beam-wheel, the bridle or clevis, and the cutting edges.

153. *The beam* — The beam in the more common forms of the plow is made of different materials and of different lengths and forms. The beam in American plows is generally shorter than in European. The beam may be either of wood, of iron, or of steel. Most of the plows used in New England have wood beams. Their chief advantages are cheapness and lightness. Several varieties of American lumber have such great strength that they are particularly fitted for use in plow-beams. Walnut and ash are among the best kinds. The advantages of iron and steel beams are great strength and rigidity. Iron beams, as made in this country, are usually short, well curved, and well adapted to rough, uneven land. Steel beams, however, which may be much lighter and still have sufficient strength, are rapidly superseding iron beams. The length, curve, and form of the beam are of importance chiefly as affecting the draft in plowing. They must be such that the point of attachment to the clevis at the end of the beam will be in a straight line connecting the center of pressure on the plow with the point where the traces are attached to the hames. The beam in most plows is fixed, but in some it is adjustable, swinging to the right or left to suit different widths of furrow. To control the depth of plowing, a clevis, which makes it possible to raise or lower the hitch, is commonly found at the end of the beam.

154. *The moldboard* — The moldboard is the part of the plow which in connection with the point of the share lifts, turns, and to some extent pulverizes the furrow-slice. The shape of the moldboard affects the work done more than any other factor. Stated as simply as possible, the following are the most essential points : The more nearly the moldboard resembles the section of a spiral, the lighter the draft and the more perfectly the furrow-slice will be inverted. Such a moldboard will, however, simply turn over the furrow-slice without much breaking or pulverization. English plows are often of this type. The plows made for general work in New England have what is called a bold moldboard, the upper or rear portion being curved more sharply than the forward end. This causes the furrow-slice to break and crumble instead of rolling over and falling perfectly inverted from the moldboard. This form of moldboard increases the draft to some extent, and also increases the liability to clog. It, however, pulverizes the soil far more effectively than moldboards which are given a more moderate curve.

155. *The coulter* — There are many forms of coulters, or cutters as they are sometimes called, in use. The more common are the straight or knife coulter, the circular or disc coulter, and the jointer or skim coulter. All coulters increase the draft and the ordinary knife or disc coulters should not be used unless necessary to enable the plowman to do good work. The disc coulter is most useful in land where the surface is covered with litter of any kind which tends to drag with the plow. It will roll down upon and cut such material as straw and cornstalks to a greater extent than coulters of any other form. The jointer is rapidly coming into use and is very effective in turning sod or plowing in green manures. All coulters should be kept sharp.

156. *Beam-wheels* — The beam-wheel or truck should be used simply to steady the plow and not to regulate the depth of the furrow. If properly used the beam-wheel slightly lessens the draft, as shown by the experiments of Sanborn and others, but if the beam-wheel is used to push up the end of the beam and control the depth of the plowing it increases the draft. The beam-wheel properly used lessens the effect of the motion of the

horses and the swing of the evener and whiffletrees and causes the plow to run somewhat more steadily.

157. *The bridle or clevis* — The clevis or bridle are names given to the metal parts at the end of the beam by means of which the plow can be adjusted to cut at different widths and depths. To increase the depth of plowing the hitch must be raised; to decrease it it must be lowered. To increase the width of plowing with the ordinary right-hand plow the clevis must be swung to the right; to decrease the width, to the left. In plows, the draft of which is heavy, an iron rod sometimes runs beneath the beam from the standard through the clevis. This is known as a draft-rod and one is shown in the cut of the subsoil plow (p. 96). The variations in the hitch to the clevis which have been spoken of are used principally to adjust the plow so it will do its best work in different soils, rather than to materially affect its capacity. In the case of swivel-plows, where the clevis may need changing every time the plow is turned, provision is made for conveniently doing this by means of a lever which runs from the clevis to the handles.

158. *The cutting edges of the plow* — The condition of the cutting edges of the plow, *i. e.*, of those edges which cut beneath and at the sides of the furrow-slice, is very important, because it greatly affects the kind of work the plow will do, as well as the draft of the implement. Sanborn found that the draft of a plow with a dull share was about seven per cent. greater than the draft of a similar plow with a sharp share. All the cutting edges, whether of the coulter or of the plow proper, should be thin, sharp, tough, and hard. Some plows are made with separate castings forming the vertical cutting edges. These when dull can be taken off and ground or they may be replaced at small cost when badly worn.

159. *The wearing surfaces of the plow* — The condition of the wearing surfaces of the plow proper greatly affects draft and the work done. These surfaces should be hard, smooth, and bright. They should be composed of metal which will not rust too easily and which will scour and keep bright in any soil. Steel or iron which is especially chilled or hardened is much superior to ordinary cast iron, on account of the better

condition in which the wearing surfaces keep and the greater durability of the plow.

160. *Classes of plows used in ordinary tillage* — There are a considerable number of distinct classes of plows, any one of which may have its advantages under special conditions. In each class there are wide variations in the details of construction, quality of material, strength, and durability. The more important classes are: landside plows, swivel-plows, sulky plows, and gang-plows. The power used in plowing may be either animal, steam, or electricity, the two latter being applied as a rule only with gang-plows.

161. *The landside plow* — The landside plow is the oldest of the forms under consideration. It is adapted to turning a furrow only in one direction, usually to the right, although plows turning a furrow to the left are made to order. These plows generally turn the furrow over more perfectly than plows which are adapted to turning furrows in both directions. They leave a dead furrow but are generally preferred for level ground.

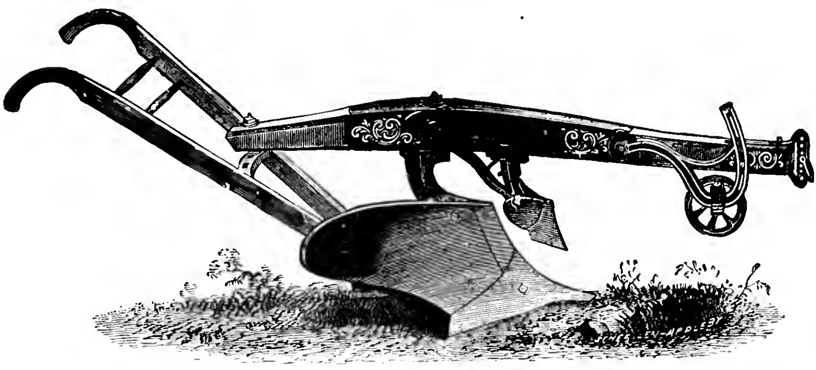


FIG. 10. LANDSIDE PLOW.

Fig. 10 shows a plow with beam-wheel and jointer with bold moldboard. This plow is adapted to heavy soils. It may also be used in sod or stubble land.

Fig. 11 shows a plow with steel beam, beam-wheel, and jointer. It has a less bold moldboard than Fig. 10, and its effect in pulverizing the heavier

soils would not be as good as that of a plow of the first type. In plowing stubble land the jointer may be removed from either of the plows. If needed, either a knife or disc coulter can be used in place of the jointer.

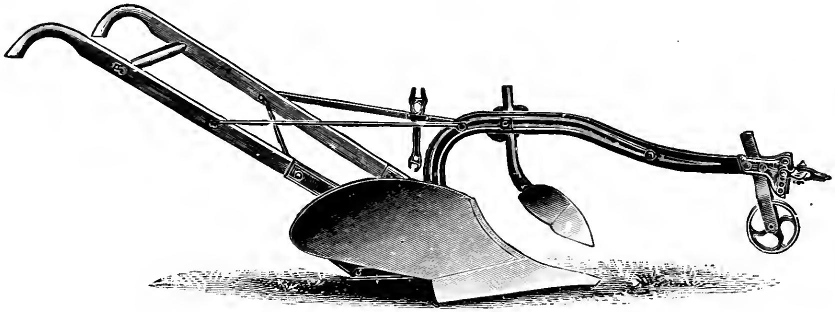


FIG. 11. STEEL BEAM PLOW.

162. *Swivel-plows* — Plows of this class are so made as to turn the furrow either to the right or the left. The furrows of a field, accordingly, can all be turned in one direction and the entire field left level and without dead furrows. These plows were at first perfected especially with reference to using on hillsides, where the dead furrows, serving as channels for water, were particularly undesirable. They are now, however, largely used in some parts of the country for all kinds of land, although as a general rule they do not turn the furrows quite as well as the best landside plows.

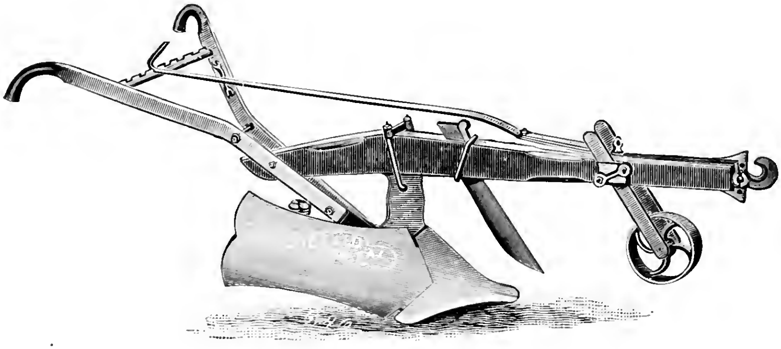


FIG. 12. SWIVEL-PLOW.

Fig. 12 shows a swivel-plow with wood beam which is perhaps one of the best of its class. This has a knife-coulter, and can be used for either sod or stubble land. The lever which runs to the rung in the handles permits ready shifting of the clevis when the plow is turned at the ends of the field.

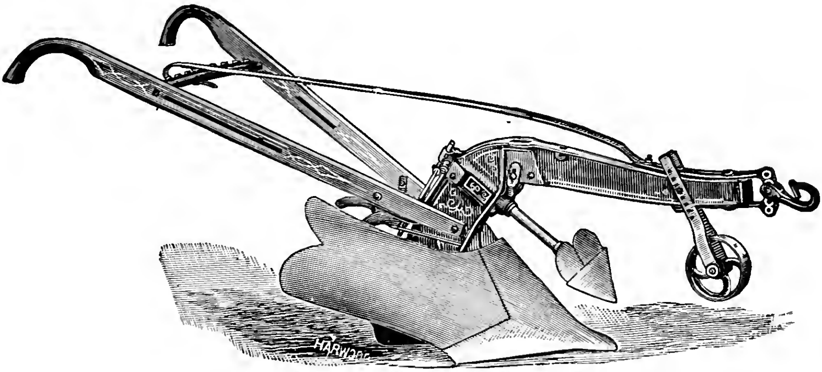


FIG. 13. SWIVEL-PLOW.

Fig. 13 shows an iron beam swivel-plow with jointer. This should be well adapted to sod land.

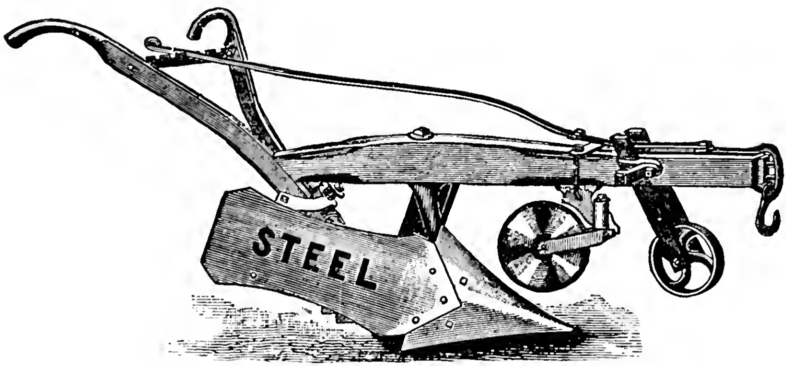


FIG. 14. SWIVEL-PLOW.

Fig. 14 shows another swivel-plow adapted to much the same work as the plow shown in Fig. 12. It differs from that chiefly in having a disc or rolling coulter in place of the knife-coulter. It is a heavy plow adapted to use in strong sod or stony ground.

163. *The sulky plow* — In plows of this type we have the plow proper carried on a pair of wheels and controlled by a lever within reach of the operator, for whom a seat is provided. The plow proper in implements of this type may be either of the landside or swivel pattern, but in some of the most successful there are two landside plows, one a right hand, the other a left hand. The details of construction differ in different makes, but

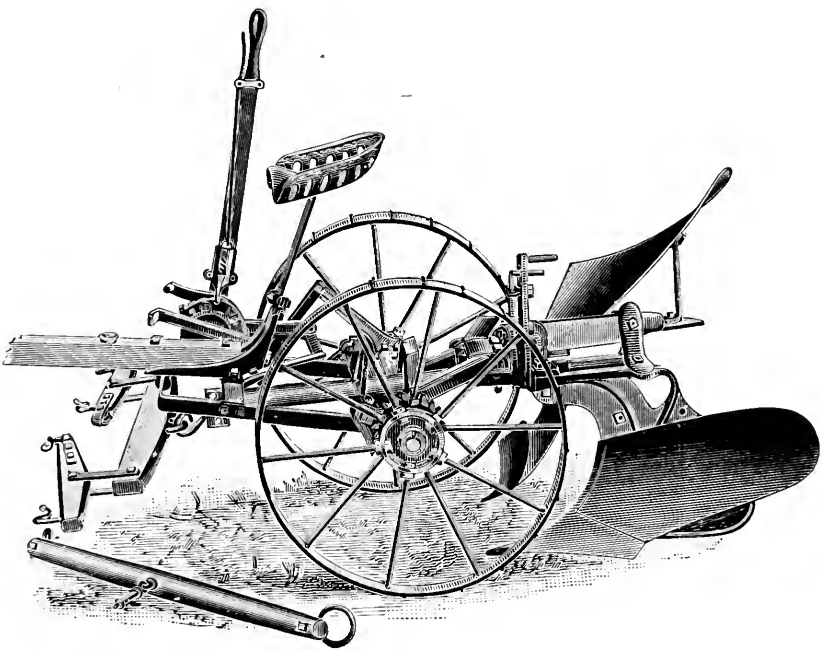


FIG. 15. REVERSIBLE SULKY PLOW.

in all these the plows are alternately brought into position for work. There is difference of opinion as to the draft of plows of this type as compared with the ordinary unmounted plows, and the truth appears to be that on firm land where the wheels do not cut into the ground the draft of the sulky plow is lighter than that of the drag plow, but where the wheels cut into the land the draft of the sulky may be the greater. The sulky plow, fixed and held firmly in position when well adjusted, with good driving, turns a very true

furrow of full depth and width. These plows are not adapted to very stony or hilly land nor to small fields. They are especially valuable in level land in hard, dry, or root-bound soils where it is difficult to keep a walking plow in the ground.

A plow of this type can be operated by a pair of heavy horses, but where moderately deep plowing is desired much more satisfactory work can be done with three. This plow is provided with jointers and can be used either in sod or stubble land. It turns a furrow considerably wider than the average of ordinary plows.

164. *Gang-plows* — In plows of this type two or more shares are attached to a frame adapted for the purpose and turning several furrows at a time. The gang-plows may be either of the sulky type (the plowman riding) or they may be carried by small wheels (the plowman walking). Such plows are useful only where the fields are comparatively large, fairly level, and free from obstructions. In fields of this character they decrease the cost of plowing per acre by decreasing the number of men employed. The number of plows in a gang, when operated by horse power, usually varies from two to four, and as many furrows are turned at one time. The team required will of course vary with the number of furrows turned.

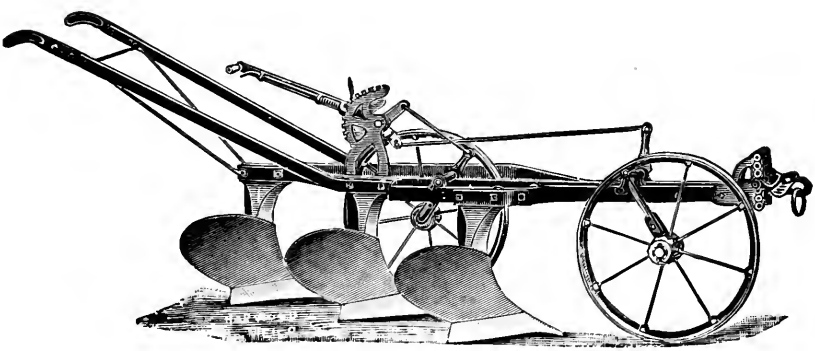


Fig. 16. Gang-Plow.

Fig. 16 shows a three-furrow gang-plow of the walking type, to operate which at ordinary depths would require from four to six horses.

Fig. 17 shows a two-furrow gang-plow of the riding type. To operate this would require four horses, and if these be good walkers one man should plow about five acres a day.

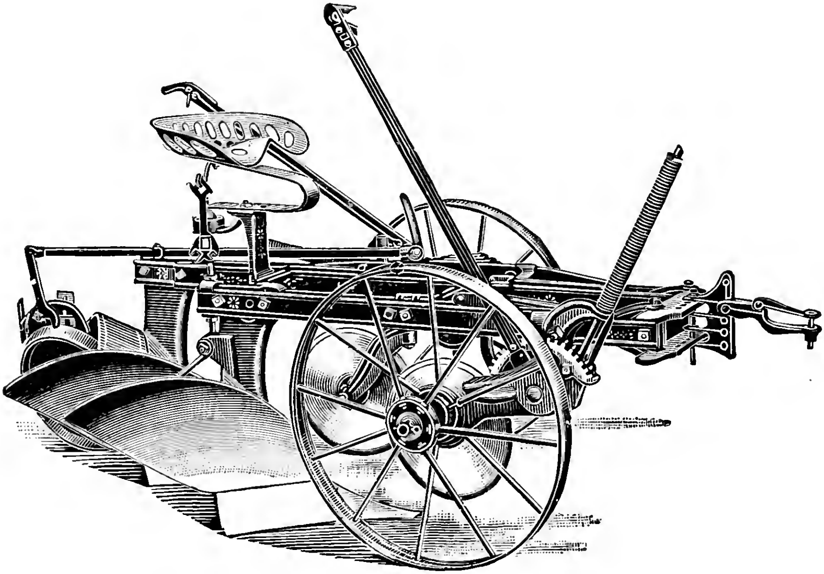


Fig. 17. Riding Gang-Plow.

165. *The motive power in plowing* — Under the conditions prevailing upon most American farms the cheapest motive power up to the present time has been either the ox, the mule, or the horse.

(*a*) Even with favorable conditions for the employment of steam existing in some parts of our West, steam power has not usually been able to successfully compete with horse power. Steam as a motive power in plowing is much more largely employed in England and on the continent of Europe than in the United States. This appears to be due to the fact that thus far horses and the food of horses have been cheaper here than in those countries, while in those countries machinery and the fuel needed to run it have been cheaper than here. There are numerous systems of employing steam in plowing. There is first the traction engine system. In this system the engine moves back and forth across the field dragging the plow.

This system has been comparatively unsuccessful in European countries but is used to some extent in some portions of the United States. The engine has driving wheels with very broad bearing surfaces and has great power, the number of plows in a gang being sometimes as great as ten or twelve. In Europe, systems employing stationary engines working wire cables to which the gang of plows is attached have been more successful. The plows used in steam plowing are reversible, *i. e.*, there are two gangs, one of right-hand, the other of left-hand plows.

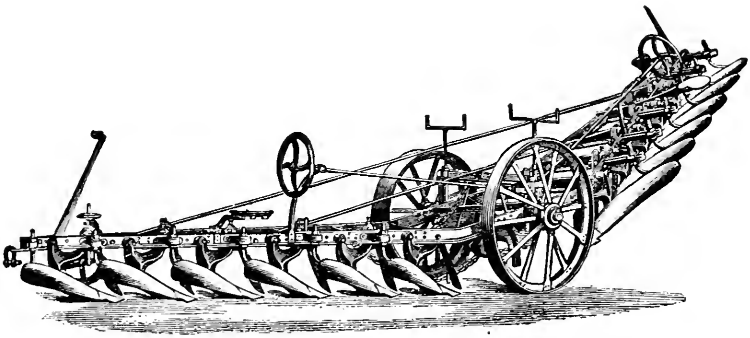


FIG. 18. GANG-PLOW.

Fig. 18 shows one of the most successful European gang-plows adapted for operation by stationary engines. The initial cost of a plant for steam plowing is of course heavy but where the fields are large, and especially if the soil be difficult to work, their use is attended with many advantages.

(*b*) *Electric plows* — Within very recent years a system of plowing employing electricity on the trolley system has been brought to a reasonable degree of perfection in Germany. It is claimed by the manufacturers that this system makes it possible to do the work more cheaply than it can be done by steam, and in that country the work is more cheaply done by steam than by horses, where the fields are large.

XXIX — PLOWING.

166. *Draft in plowing* — The draft in plowing, as has been stated, varies widely. It can be measured in pounds. It is commonly determined

by putting a powerful spring balance between the clevis and the team. Such a spring balance should be provided with a self-registering attachment, and, being used for measuring power, it is known as a *dynamometer*. The amount of power which can be steadily exerted by a pair of horses throughout a working day without over-straining is about 300 pounds. In stubble land a furrow 6 inches deep and 12 inches wide will require about this amount of power. It has been found by experiments which were first conducted by Sanborn in this country that the total draft of the plow is divided as follows: cutting beneath and at the sides of the furrow-slice consumes 55 per cent. of the total power; the friction of the plow upon the bottom of the furrow and upon the landside uses 33 per cent. of the power; while raising, turning over, and pulverizing the furrow-slice consumes only about 12 per cent. of the total power. If the strength of the pull of a pair of horses is measured by 300 pounds, then 165 pounds is required for cutting, 99 pounds to overcome friction, and 36 pounds to raise and turn over the furrow-slice, making a total of 300 pounds. Sanborn carefully investigated the effect upon the draft of some of the different parts of the plow and of varying conditions. His conclusions may be briefly stated as follows:—

1st. The use of a coulter of any kind increases the draft and the same would of course be true of the jointer.

2d. The right use of the beam-wheel lessens the draft.

3d. There is no material difference between the draft of the walking and sulky plows on level land.

4th. The draft per square inch of the cross section of the furrow-slice decreases as the depth of plowing increases, so long as the soil is of the same character and the plow not worked beyond the depth to which it is suited. To illustrate, if the furrow-slice turned is 6 by 12 inches, the area of the cross section is 72 square inches. To turn such a furrow-slice requires about 300 pounds. This is 4.1 pounds per square inch. If, now, the depth be increased to 8 inches the cross section of the furrow is 96 square inches; the draft will not, however, be 96 times 4.1 pounds, but considerably less than this.

5th. The way in which the plow is held, or, in other words, the skill of the plowman, does not very materially affect the draft, provided, of course, the plow is carefully adjusted.

167. *Objects in plowing* — The chief objects in view in plowing are the pulverization of the soil, inverting or turning over, and the burying of trash, manure, or stubble. In not a few cases the first, which is generally the most important of the objects to be attained, is neglected and the plowman is satisfied if he turns the furrow-slice completely over and buries whatever may have been lying upon the surface. This, however, is a mistake. The inversion of the soil is generally comparatively unimportant although the burying of trash and stubble if present is necessary. This can be accomplished, however, without completely inverting the furrow-slice.

Flat furrow plowing is the name used to designate that kind of plowing in which each furrow-slice is completely inverted and lies flat in the bottom of the preceding furrow.

FIG. 19. FLAT FURROW-SLICE.

Fig. 19 shows results of flat furrow plowing. It will be noticed that the furrow is comparatively little pulverized and that there are no large air spaces beneath it. This is usually the poorest kind of plowing, for the soil

is not well aerated nor pulverized. It is, moreover, difficult to bring it into proper tilth by the use of a harrow.

Lap furrow plowing is the name used to designate that style of plowing in which the furrow-slice is only partly turned over. It laps partially over the preceding furrow-slice and instead of a flat surface it leaves a ridged or broken surface.

FIG. 20. OVERLAPPING FURROW-SLICE.

Fig. 20 shows the results of lap furrow plowing with the furrow-slice comparatively little pulverized. It will be noticed that there are air spaces beneath the furrow. As a result of this method of plowing the soil is very fully exposed to the action of air and frost and it can readily be brought into good tilth by the use of harrows which break down the ridges.

Fig. 21 shows the results of lap furrow plowing with a bold moldboard, the furrow being broken and pulverized to a considerable extent. Under most circumstances this is the best kind of plowing, and except in extreme cases stubble, trash, or coarse manures can be covered sufficiently by it with the use of the jointer, which doubles over upon itself a portion of the furrow-slice.

The drying and warming of the surface soil by early spring plowing is an object which is sometimes of importance, while, according to Roberts, the plowing each year at the same depth, resulting in the formation just below the depth to which the land is plowed of a kind of hard pan, consolidated by the trampling of the horses and the weight of the plow, may be useful and highly desirable in some of the lighter soils.

FIG. 21. ROLLING FURROW-SLICE.

168. *When to plow* — We have to consider under this topic both the season and the condition of the soil. As most of our crops are put in in the spring, nearly all of the fields which are to be plowed in any one year will need plowing in the spring ; the object in view being to bring the soil into favorable physical conditions for the crop which is to be put on the field. Summer plowing is not as a rule called for, although in case of catch crops or crops grown as green manures it may be necessary. Fall plowing is carried on, first in preparation for the winter grains or fall seeding to grasses, or it may be with a view to soil improvement or to saving work in the spring. Plowing in the fall results in better exposure of the soil to the action of air and frosts; and to secure the utmost benefit through the action of these

agencies the fields should be left rough. The lap furrow and one which does not break or pulverize the soil too much will usually be best. The soils most needing fall plowing are those which incline to be heavy. Fall plowing such soils renders them more mellow and makes them work far more easily. Fall plowing, further, may be made the means of destroying or helping to destroy certain insects. For this purpose late plowing is desirable, *i. e.*, after the insects have become torpid, when, if they are brought near the surface, the exposure to winter's cold may kill them. Many wire worms may be destroyed in this way. Land which is plowed in the fall is often benefited by a second plowing in the spring. Our farmers often make the mistake of fitting the land imperfectly. Those soils which are difficult to work should sometimes be plowed several times, the harrow and roller or clod-crusher being used between the different plowings. I have known a good farmer to plow a heavy clay loam five times in preparation for a crop of onions, and such thoroughness of preparation was found profitable.

Whatever the season in which plowing is done, it is important to be guided by the condition of the soil as regards moisture. If soil be plowed either too wet or too dry it is but little pulverized. The effort should be made to plow when the soil holds such an amount of water that it crumbles and breaks into a fine meal-like condition as it is turned over. If too wet the tenacious clods thrown up by the plow, on drying, become hard and stone-like. Such a condition is highly unfavorable to the germination of seed or the growth of the crop. For most crops it is better to plow some little time before the seed is put in, because for most a moderately compact condition of the soil is better than extreme looseness. The length of the interval desirable will differ with the soil and with the crop, being shorter for the heavier soils than for others. As a rule the soil needs plowing in preparation for seed ; but some experiments which have been carried out in this country indicate that if a field has been carefully cultivated the previous year preparation with the harrow may give better results with spring-sown grains, such as oats, than plowing. These grains thrive best with a soil in a moderately compact condition.

169. *Starting the plow right* — In order to secure the desired results with the least possible expenditure of power by the team the following directions should be observed : —

1st. Hitch the team as close to the plow as may be possible, allowing the horses opportunity for free movement without striking their heels. The nearer to the load, within ordinary limits, the less the draft.

2d. Raise the beam-wheel as high as possible, hitch to the lowest hole in the clevis, start the plow and note whether the furrow is sufficiently deep. If not, raise the hitch one hole at a time until the plow cuts at the right depth.

3d. Note whether the furrow is turned over properly. If it goes over flat, and a lap furrow is desired, it is because the furrow is too wide in proportion to its depth, and the clevis must be moved to the left. If, on the other hand, the furrow stands on its edge or too nearly on its edge, the furrow is too narrow in proportion to its depth, and the clevis must be moved in the opposite direction.

4th. When adjustment is so made that a furrow of the right depth is turned and left at the right angle, the plow should run in soil free from stones or other obstructions even without holding, maintaining perfect balance and cutting a furrow of even depth and width. If it will not do this either the plow is a poor one, or, what is more likely, it is not correctly set up or adjusted. When at last the plow will run in any soil for some distance without holding, then the beam-wheel should be moved down until it just touches the surface, rolling over it without much pressure. Thus adjusted the plow will do its best work, and the team will find the work as easy as it can be made.

170. *General hints on plowing* — The jointer is especially useful in two directions : turning over a narrow lap on the edge of the furrow, it enables the plowman to cover sod or stubble of any kind much more perfectly than is possible without it. When sod is plowed without the jointer a line of grass is likely to start between the furrows. With a jointer properly used this does not take place. In the second place the jointer helps to prevent the furrow from turning over too flat. It should be remembered

that the width of the furrow turned by any plow is affected by the relative depth and breadth of the furrow. If the breadth is much more than one-half greater than the depth, the furrow is turned over relatively flat. When the breadth is just about one and one-half times the depth the furrow is left at about the right angle. With all heavy soils the lap furrow is far superior to the flat. With lighter soils it does not so much matter if the furrow be flat, for such soils are easily brought into good tilth whatever the kind of furrow turned. If sod on heavy soil, however, be turned over flat, that soil cannot be brought into good tilth until the sod has rotted. The decision whether or not a given field should be plowed should depend upon whether or not plowing is necessary to procure a good seed bed. If not, plowing should be dispensed with, as it is the most costly operation in fitting land for seed. Every farm must as a rule have two plows, one for sod, the other for stubble land. Never plow without first thinking if it is necessary, and, having decided to plow, never plow without thinking what kind of plowing will leave the land in best condition for what is to follow. The depth to which it is desirable to plow is determined in part by the soil and in part by the crop. For orchards and root-crops deeper plowing is needed than for most, and the heavier soils, as a rule, require deeper plowing than the light. It should be remembered that soil which has never been brought to the surface is in one sense raw. Whatever food it may contain is largely unavailable. If, then, it be decided to deepen the soil by plowing more deeply, it should be done gradually, for if too much of the raw soil is brought to the top the productive capacity of the land is for a time decreased. It is not safe to deepen a soil at the rate of more than about an inch a year for the ordinary crops of the farm. In preparation for orchard trees, which root much more deeply than most crops, a larger amount of the previously undisturbed soil may be turned up at one time.

XXX — HARROWS AND HARROWING.

171. *Kinds of harrows* — There is almost infinite variety in the details of the construction of harrows and in the principles upon which they work, but most of the leading and most useful forms are included under the fol-

lowing classes: spike-tooth or scratching harrows, coulter harrows, disc harrows, and spring-tooth harrows.

172. *Spike-tooth harrows* — The original form of the square or A-shaped spike-toothed harrows is not much used for general work by progressive farmers at the present time, but that form of the smoothing harrow so made that the teeth may stand either straight or sloping to the rear when in use may properly be included in this class, and harrows of this construction are still much used. These harrows have more numerous and smaller teeth than the original forms of the spike-tooth harrow.

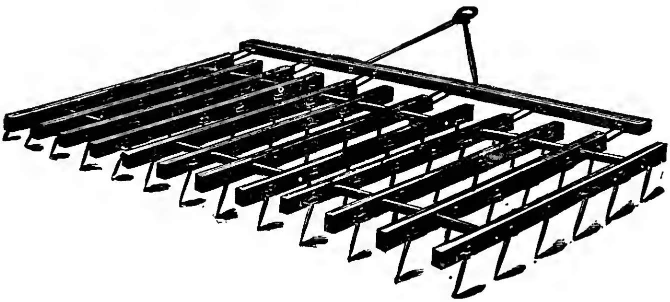


FIG. 22. SMOOTHING HARROW.

Fig. 22 shows a common form of harrow of this class. These harrows are known as smoothing harrows and they are particularly useful in leveling inequalities of the surface, fining the surface soil, and in the interculture of some crops in the earlier stages of their growth. The cut shows this harrow in position to work with teeth sloping to the rear. By drawing it from the opposite side the teeth are brought into an upright position. By this change the harrow is made to work more deeply but is less efficient as a smoothing implement. When used with the teeth sloping to the rear the smoothing harrow has a considerable tendency to compact the soil. In many cases harrows of this type have steel frames and are provided with shoes on which they may be easily moved from place to place.

173. *Coulter harrows* — These harrows do work similar to that of a gang of small plows, cutting through the soil and at the same time raising and turning it to a certain extent. Harrows of this class are perhaps best

represented by the Shares and Acme harrows. Such harrows will work to the depth of from one to four inches. They are very effective in pulverizing the surface of newly-turned sod land, not turning up the sod to nearly the same extent as harrows of some other types and not being of as heavy draft as disc harrows, which are adapted to work of somewhat the same character.

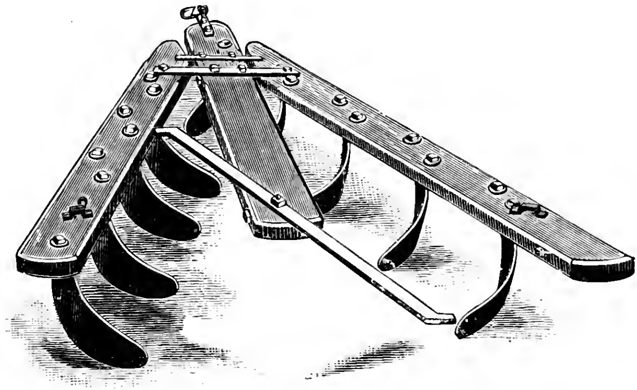


FIG. 23. SHARES HARROW.

Fig. 23 shows the Shares harrow. One of the most serious objections to this harrow is its weight and the difficulty of moving it from field to field.

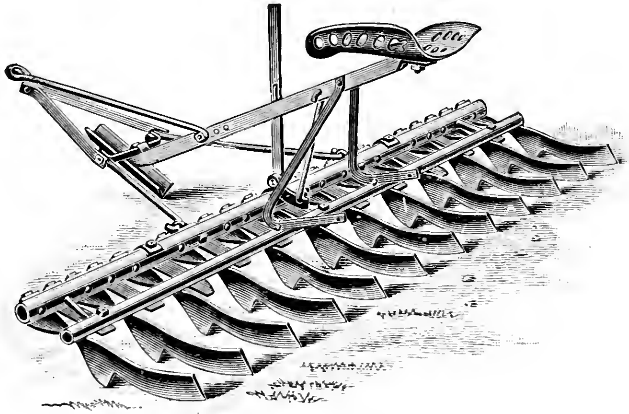


FIG. 24. ACME HARROW.

Fig. 24 shows one of the forms of the Acme harrow. This is without doubt one of the most perfect harrows thus far invented. It has a wide range of adjustability, will work at various depths, and is very effective in leveling, smoothing, and pulverizing the surface soil. In very tough sod the Shares or the disc harrow may be more effective, but under ordinary conditions the Acme does exceedingly good work.

174. *Disc harrows* — This class includes all harrows which cut or pulverize the ground by means of revolving discs, and we may class with them harrows of the spading and cutaway types, which are, indeed, disc harrows in principle with larger or smaller sections of the discs, as it were, cut out. These harrows work the soil more deeply than any other form. They are very extensively used and are the most effective type of harrow for pulverizing tough sod land.

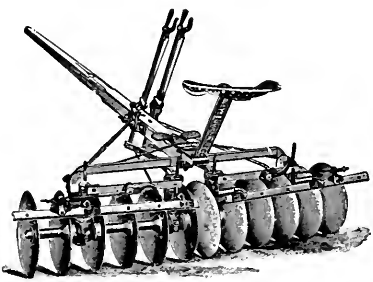


FIG. 25. DISC HARROW.

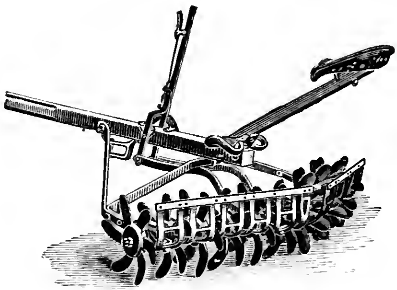


FIG. 26. SPADING HARROW.

Fig. 25 shows a disc harrow. This type appears to be generally more popular than the spading and cutaway types, perhaps largely because it is more durable. The discs must be kept sharp to secure the best results. That portion of the soil below the depth to which the discs cut is undoubtedly somewhat compact by the use of harrows of this type. One of the chief objections to them is their heavy draft. They must generally be followed by some form of surface or smoothing harrow to level the surface ridges and to more thoroughly fine the upper surface.

Fig. 26 shows a spading harrow. Harrows of this type will work to somewhat greater depth than the disc harrows, but they are more likely to be injured or broken in stony land and are not very widely employed.

Fig. 27 shows a Meeker harrow, which is so different in its construction from other disc harrows that it perhaps hardly belongs in this class. As will be seen from the cut, however, the working part of the harrow consists of a series of small discs set on revolving rollers, these rollers in turn being set in a rectangular frame. A harrow of this type is much used by market gardeners in some sections in smoothing and fining soil in preparation for onions and similar small crops. The use of this implement makes it possible to prepare a very fine seed bed without the use of the hand rake.

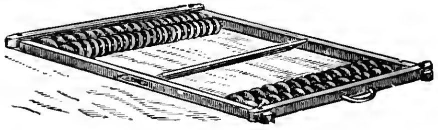


FIG. 27. MEEKER SMOOTHING HARROW.

The draft of harrows of the disc, cutaway, and spading types is somewhat above that of a plow at ordinary work. According to Sanborn it varies from about 326 to 369 pounds (166).

175. *Spring-tooth harrows.* This class of harrows includes all those which tear the ground by means of curved spring teeth of steel. They are generally made with steel frames and are very durable. The teeth, by means of levers provided for the purpose, can be set at various angles, which greatly affects the kind of work the implement will do. As sometimes used these harrows tend to tear up the turf on sod land or to bring trash which has been buried by the plow to the surface, but if the teeth are turned at the right angle, the tendency in this direction is much diminished. These harrows leave the soil quite light. They are often especially useful in orchards, as the teeth will spring over the roots without liability to breakage. On rough land the draft is apt to be uneven, and this sometimes leads to galls on the shoulders of the horses.

Fig. 28 shows a spring-tooth harrow of one of the latest types. The draft of harrows of this class, according to Sanborn, varies from about 275 to 290 pounds, being, therefore, a little less than the draft in plowing. It would seem, however, that in different adjustments there must be a wider variation than Sanborn's tests indicate, and practical experience seems to show that if the spring-tooth harrow be set to run deep the draft is heavy, or at least, possibly because of its jerky character, more wearing upon a team than an ordinary plow.

176. *Harrows of the same types vary* — In the cuts which are here used the Shares, Acme, and spring-tooth harrows are shown without seats. They are sometimes made with seats on which the driver rides. The extra weight of the driver is sometimes useful, making it possible to work the harrow at a greater depth than it will naturally run. Where this is desirable it seems better that the driver should ride, but where the weight is not required the driver should walk, as the draft of the harrow of many types is heavy, and it should not be needlessly added to. Each of the

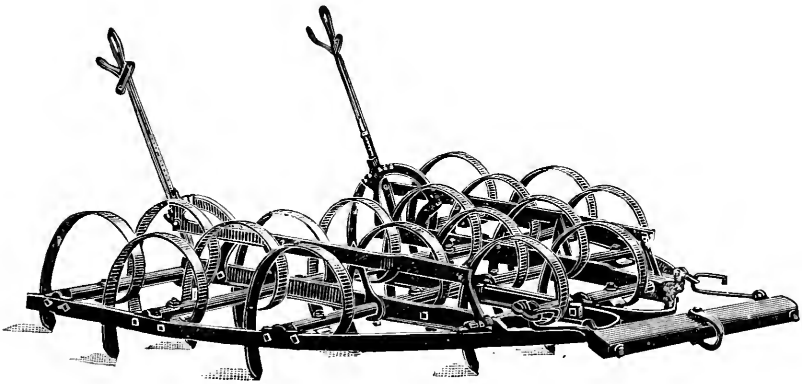


FIG. 28. SPRING-TOOTH HARROW.

different classes of harrows is usually made in a number of different widths. We find the greatest variations in the smoothing harrows. These, within certain limits, do better work the wider they are made. On large farms of the prairie regions of the Middle West, one of these harrows sometimes covers a width of forty feet, and forty acres per day can be gone over by a single man. To operate a harrow of this width four horses are required. The use of wide harrows undoubtedly makes possible a very considerable saving in human labor, and on large farms it would seem desirable that coulter, Acme, and spring-tooth harrows of as great a width as possible should be employed, the number of horses being increased if necessary.

177. *Harrowing* — There is no single harrow suited to all classes of work. To do complete work on all kinds of soils requires several kinds. The Acme harrow is undoubtedly suited to a wider variety of work than

most of the others, but on a farm of any considerable size it will commonly be found necessary to have one of the deep cutting harrows, such as the disc or Shares, and a smoothing harrow. The first will be used immediately after the plow to do the rough pulverizing of the soil, and should be followed by the smoothing harrow to finish for most kinds of seeds. The smoothing harrow, moreover, will be very useful in interculture, a use to which none of the other types of harrows is adapted. In the greater majority of instances conservation of the moisture of the soil to as great an extent as possible is desirable, and in all such cases harrowing should follow promptly after plowing. If the soil be plowed when containing the right amount of moisture for the best work, then the sooner it is harrowed the more effective the work of the harrow will be. If the soil be allowed to remain rough as left by the plow, its exposure to the air causes it to dry out rapidly, hard clods are formed, and these cannot readily be broken by the harrow; while if this implement follow closely after the plow, it finds the lumps of earth soft, and they are therefore comparatively easily broken. There are, of course, cases where exposure to the weather or some drying is desirable, and in such cases the rough furrow should be left for a time (167, 168). Under exceptional circumstances land may be fitted for seed without plowing (168). For this purpose harrows of the disc pattern should generally be first used.

XXXI — ROLLERS AND ROLLING.

178. *Objects of rolling* — The principal objects in view in rolling are to crush the lumps and to compress the surface soil, thus improving its capillary qualities and enabling it to conduct water from below in greater amount either to the freshly-planted seed, which must have considerable moisture in order to germinate, or to the roots of a growing crop. The roller is an important tillage implement, but must be used with discretion. Water will evaporate from the smooth surface of a rolled field in much greater amount than from a similar soil where the surface portion is light, as it would be left by the smoothing harrow or weeder. It may, therefore, in some cases be desirable after crushing clods and somewhat compacting the too mellow soil

to follow with a fine-tooth, shallow-working harrow or weeder in order to form a light mulch of mellow soil at the surface. There are cases also when injury from wind, which tends to sweep away the finest and best portions of the soil, will follow if fields be left smooth after rolling. There will be less loss from fine soils in exposed localities if, after rolling, the surface be roughened by the use of a harrow. There is still another use of the roller which is sometimes of considerable importance, viz., pressing small stones into the soil. This is one of the chief objects usually in view in the use of the roller after seeding land to grass.

179. *Kinds of rollers* : —

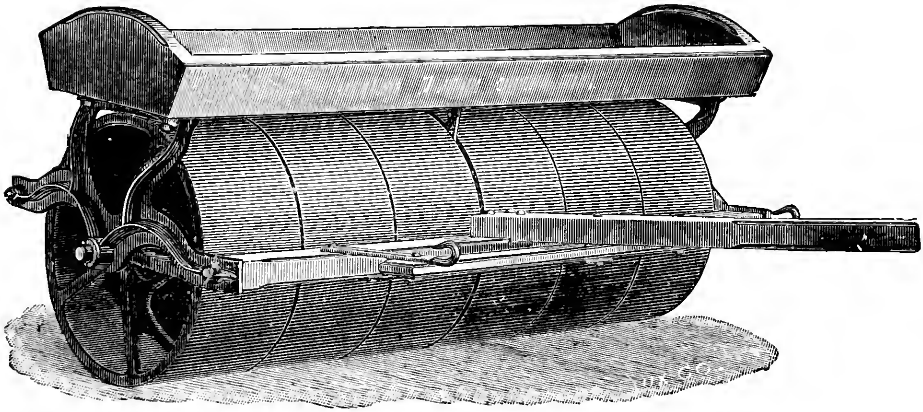


FIG. 29. IRON FARM ROLLER.

Fig. 29 shows an iron farm roller. Rollers of this kind may be too heavy for use in some cases, but they are much the most durable, and for many kinds of work must be regarded as the best type. The box carried by this roller is useful as a receptacle for stones or other material which needs to be picked up when land is seeded to grass. A roller made in sections like the one shown will do smoother work in turning at the ends of a field than an implement with a single or a lesser number of sections. Wood rollers, being lighter, are preferred by some. These are commonly made in two sections. They are fairly durable implements, and the first cost is of course considerably less than that of an iron roller. Inventors

have from time to time put out under such names as pulverizers or combined rollers and pulverizers, implements in which, instead of plain cylinders, cylinders with corrugated surfaces, or cylinders made up of a series of blades and crushing bars set in cylindrical heads, are substituted. It is claimed for these that they are far more effective in breaking up and crushing the clods. While this may sometimes be the case, it seems doubtful whether under ordinary conditions there is likely to be any very great difference in effectiveness in this direction, and it cannot be doubted that on all the loams of medium or heavy type the adhesion of the earth to the surface of the roller, except at times when it is unusually dry, will be likely to convert implements of this type into practically smooth rollers.

180. *Clod-crushers or drags* — These implements are a cheap and under many conditions a good substitute for the roller. They are usually home made, and consist of planks fastened together in the form of a drag, or, as it is known in some sections, a boat. If the planks are lapped, shingle-fashion, the implement is more effective than if smooth on the bottom. The clod-crusher is superior to the roller where it is desired to smooth the surface and break the lumps and not to compact the soil to any great degree. They are not equal to the roller for pressing small stones into the ground, but, like the roller, they may be used in carrying off stones or rubbish. They are often employed to prepare the surface for marking in preparation for crops like corn and potatoes.

XXXII — CULTIVATORS AND CULTIVATING.

181. *Kinds of cultivators* — As is the case with most other kinds of farm implements, there is an almost endless variety of cultivators, and each of the various forms may be suited to certain conditions or the accomplishment of certain kinds of work which may be desirable. The farmer in selecting a cultivator must keep in mind the results which he wishes to produce and must choose the kind or kinds of cultivators best calculated to secure these results. Cultivators may be classified according to a similar plan to that which has been adopted for harrows. Under this system we must recognize the following classes: spike-tooth cultivators, coulter or

shovel cultivators, disc cultivators, spring-tooth cultivators, and sulky cultivators.

182. *Spike-tooth cultivators:—*

Fig. 30 shows a good type of this class of implements. The discs shown on either side are of course not needed for ordinary work. They are designed for cutting the runners in the culture of strawberries and are removable. It will be noticed that the teeth are double-ended. If the implement be used in the position shown, it will run somewhat deeper than would be the case with the teeth reversed. The lever between the handles is used in controlling the width at which the implement works. This can be quickly changed by moving the lever either forward or backward. Cultivators of this type may be used for fining the surface soil and in maintaining the surface mulch. They are selected in cases where comparatively shallow culture only is needed and where throwing the earth against the growing plants is undesirable. They leave the surface level and comparatively smooth.

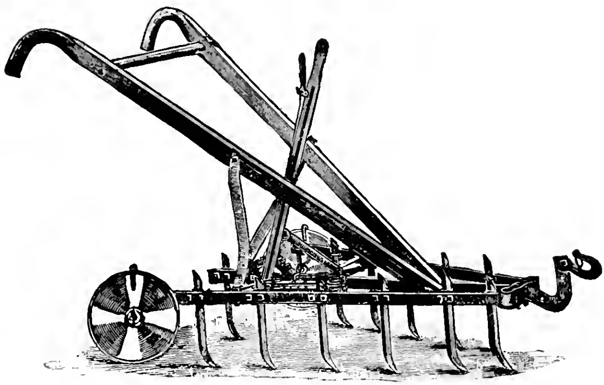


FIG. 30. SPIKE-TOOTH CULTIVATOR.

183. *Coulter or shovel cultivators:—*

Fig. 31 shows a cultivator coming under this class. We have within the class a very wide variety as regards form and size of the coulters or shovels as they are sometimes called, and in short in all the details of construction. The cut shows one of the most generally useful forms of one-horse implements adapted for use between the rows. This implement has a wide range as to adjustability of width and depth of working. It works to moderate depth and leaves the soil slightly roughened but does not hill up or ridge the crop to any considerable extent. If this kind of

work is desired, hilling wings will be furnished with the implement. These are readily put on or removed. Implements belonging in this class are sometimes known by the name of horse hoes. There appears to be no well defined difference between so-called cultivators and horse hoes, and the use of the latter term is not apparently necessary.

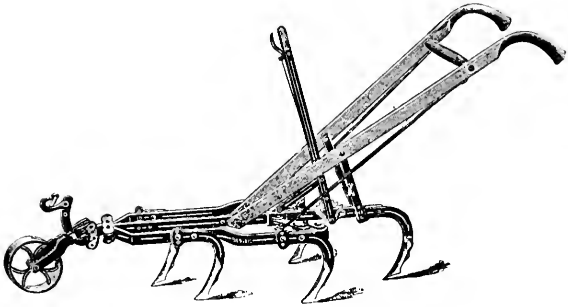


FIG. 31. COULTER OR SHOVEL CULTIVATOR.

184. *Disc cultivators*—The working part of cultivators of this type is a series of discs usually of similar construction to those used in disc harrows though they are often smaller in size. These cultivators do not appear to be looked upon with much favor and are not yet extensively used. One of the most common of the cultivators of this class is of the so-called sulky type.

Fig. 32 shows a disc cultivator adapted to work on both sides of the row at one time. The discs can be set by a lever at different angles to throw soil toward or from the row. It can be adjusted to any width and can be set to cut deep in the center and shallow next the row, or the reverse, or level. An implement of this class might very effectively cut up and bury weeds, but in inter-tillage of crops it is better policy to destroy weeds before they are large enough to require an implement of this type.

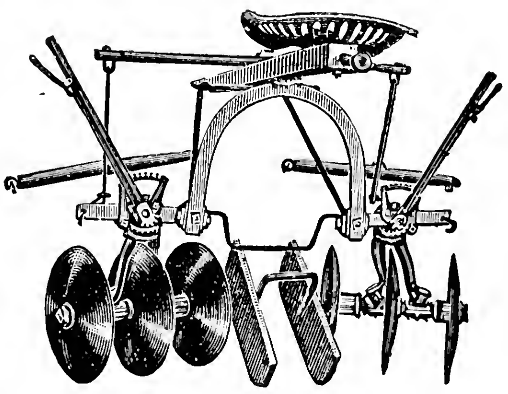


FIG. 32. DISC CULTIVATOR.

185. *Spring-tooth cultivators:*—

Fig. 33 shows a one-horse, spring-tooth cultivator. This implement would have about the same merits and defects as a spring-tooth harrow. It is not a type which is as yet much used and, in view of the general preference for shallow culture, it seems doubtful whether it will become important.

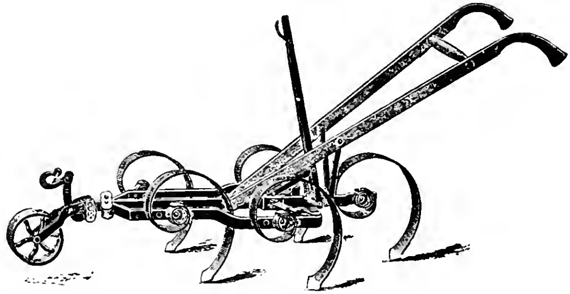


FIG. 33. SPRING-TOOTH CULTIVATOR.

186. *Sulky cultivators* — There is very wide variation in the details of construction in this class of cultivators. All, however, are provided with moderately high wheels. The working part of the implement may be either of the scratching, coulter, spring-tooth, or disc type; but is most often of the coulter or shovel pattern. Any one of these styles may be either of the riding or walking type.

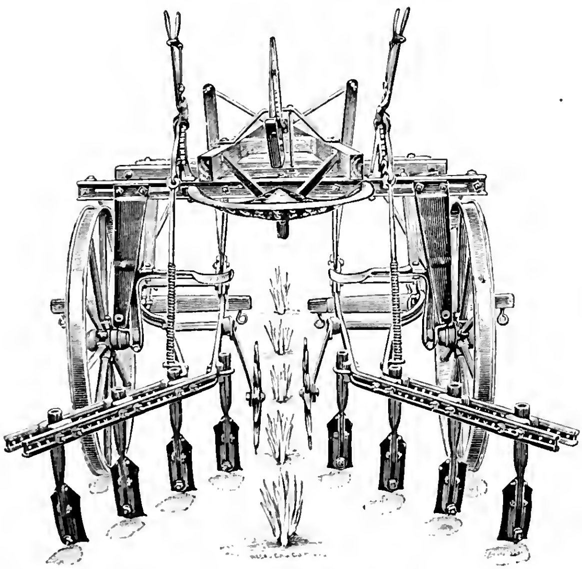


FIG. 34. SULKY CULTIVATOR.

Fig. 34 shows a sulky cultivator of the riding type. It will be noticed that the working parts or shovels are in two gangs adapted to working on both sides of a row. It will be further noticed that there is a special adjustment to prevent the throwing of earth on the plants while they are small. These parts are readily

removable and are not needed after the plants have reached a height of five or six inches. The driver guides the shovels by the use of his legs, his feet resting in stirrups provided for the purpose. With most implements of this pattern extra shovels are provided and on being added to the inside of any gang the cultivator will completely cover the soil for the full width between its wheels. It is often used in this form as a harrow before the planting of the crop.

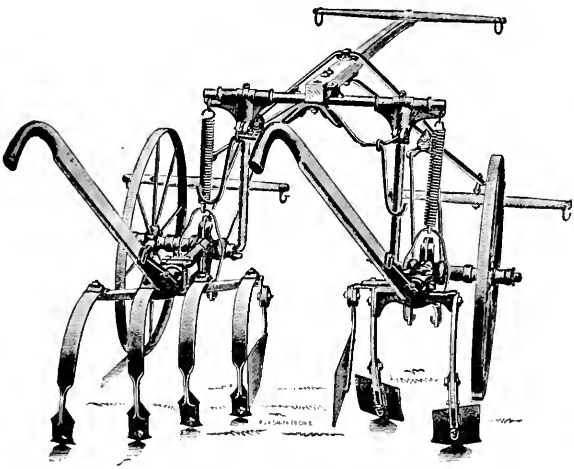


Fig. 35. Sulky Cultivator.

Fig. 35 shows a sulky cultivator of the walking type. It will be noticed that the two sides of the implement are shown to be different. It is not expected, however, that the implement will be used in this way. The two sides are so shown to indicate the extent to which the implement can be varied. The purchaser would be able to buy either or both sets of shovels. Cultivators of the sulky pattern are almost the only kinds used on the large farms of the corn-growing sections of the United States and they should be more generally used in the East than is the case. Many of those who have had large experience in the use of the two types, the riding and walking, prefer the latter, finding that the workman when on foot is more likely to guide the implement carefully, thus avoiding damage to the crop. It is evident, also, that the draft of the implements of the walking type must be considerably less than that of the riding implements.

187. *Cultivating* — The various types of cultivators are used almost exclusively for interculture, the objects in view being the killing of weeds, the pulverization of the soil, and the conservation of moisture. Frequent

shallow cultivation is the watchword in modern agriculture. It is now believed that the deep tillage of former years has been harmful ; first, because bringing moist soil from a considerable depth to the surface and leaving the surface rough there has caused a great loss of soil moisture, and, second, because the roots of the growing crop have been torn and broken. Level culture, under almost all circumstances, is best. Hilling or ridging increases the amount of surface exposed to the air and is apt to lead to the destruction of a portion of the growing roots. It should not, therefore, be practiced unless to accomplish some specially desired object as, for instance, to cover potatoes which tend to grow exposed to the air, or sugar beets to secure the better quality which is obtained when the roots grow wholly under ground. In this case on ordinary soils the ridges should be broad and not higher than is essential to accomplish the object in view.

188. *Weeders* — The weeder is an implement chiefly used in the interculture of crops. It is adapted to stir a wide section of the soil to small depth and leaves the surface smooth and level. All the various forms of weeders are provided with rows of long, flexible steel teeth which act on the ground in much the same manner as would the teeth of a common spring-tooth rake. The teeth of the weeders, however, are not curved forward at the lower end as are those of the rake, and they do not therefore run as deep nor tear up the ground to as great an extent as would the rake. Weeders are very useful in keeping the soil mulch in proper condition. They will pass over young crops such as corn and potatoes, while these are small, without much injury to the crop. They are very effective in the destruction of weeds if used just as the latter are vegetating, but not nearly as effective if the weeds be allowed to get thoroughly rooted. Weeders may be used with corn until it is two feet in height and some use no other implement. In the majority of instances, however, a cultivator which works somewhat more deeply will be preferred for the later cultivation of this crop. Weeders are made with straight, curved, rounded, and flat teeth.

Fig. 36 shows a type of weeder with curved, round teeth, which is much used in the eastern United States. These are sometimes made on the one hand much wider, or on the other hand narrow enough to go between the

rows of such crops as corn. The broad weeders are the more useful in large fields, and there appears to be little demand for the narrow form.

Fig. 37 shows an adjustable weeder. This works upon essentially the same principles as the one shown in Fig. 36, but the working width can be

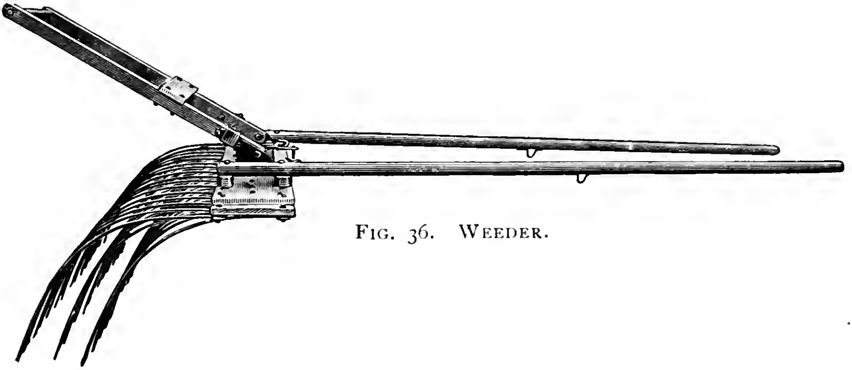


FIG. 36. WEEDER.

varied from about 30 inches to 7½ feet. This type of weeder seems likely to prove very useful on farms on which a variety of crops and soils is found. All types of weeders, while used chiefly in interculture of crops, may sometimes with advantage be used in covering small grains and grass seeds sown broadcast.

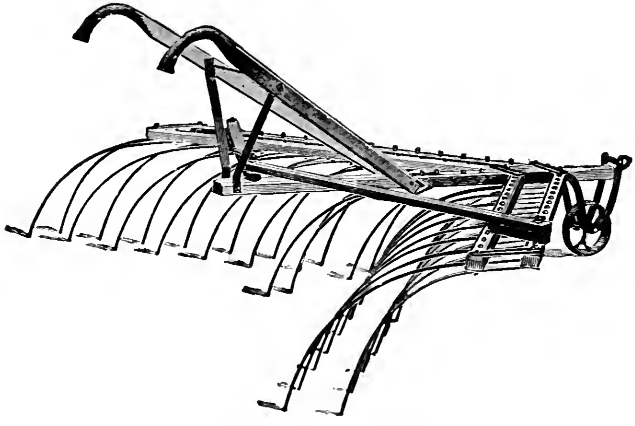


FIG. 37. EXPANDING WEEDER.

XXXIII — HAND IMPLEMENTS.

189. *Classes* — The various hand implements which are used in tillage operations are for the most part exclusively employed in the inter-tillage of crops which are planted so close as to make the use of implements drawn by horses impossible. They are also used in stirring the soil and destroying weeds at points not reached by the horse-drawn implements. There are several quite distinct classes, and in each a wide variety. The most important may be included under the following heads: cultivators, scuffle or shove-and-wheel hoes, hand hoes, rakes, and weeders.

190. *Hand cultivators* — These exhibit similar varieties to those found among horse cultivators as regards number, size, and shape of teeth employed. The best hand cultivators are provided with a number of interchangeable teeth, fitting a single implement for different uses. There is

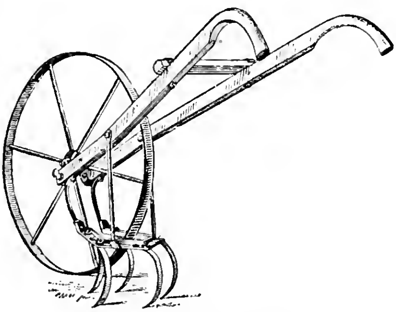


FIG. 38*a*. SINGLE WHEEL HAND CULTIVATOR.

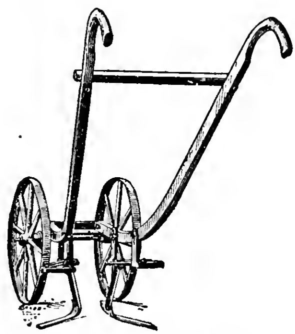


FIG. 38*b*. TWO-WHEEL HAND CULTIVATOR.

wide variation in the wheels of these implements; some are provided with two, others with a single wheel. Those with a single wheel are adapted to working between the rows, those with two wheels usually work astride the row. Implements with large wheels and broad tires run more easily than those with small wheels. Implements of this class may be quite effective in pulverizing the soil and maintaining a surface mulch. Figs. 38*a* and 38*b* show a single and a two-wheel hand cultivator.

191. *Scuffle or shove-and-wheel hoes* — Figs. 38*a* and 38*b* show the two leading types of implements coming under this class. The working part is

a flat blade which in operation cuts just beneath the surface. These implements are useful in the destruction of weeds, but do not mellow the soil to any considerable extent. The scuffle hoe, or wheelless type, is much employed in some sections by onion growers, but the wheel form, it is believed, should generally be preferred, except when the tops are large, after which the form without wheels is preferable.

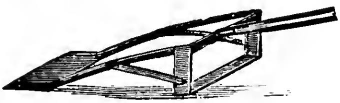


FIG. 39*a*. SCUFFLE HOE.

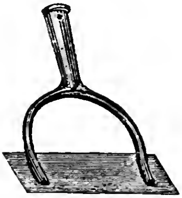


FIG. 39*b*. SCUFFLE HOE.

192. *Ordinary hoes and rakes* — The ordinary garden or field hoe and rake are too well known to require extended notice. These implements were formerly far more used than at present. While they will be needed on every farm, and must be employed in certain kinds of work, the intelligent farmer restricts their use to as great a degree as possible.

FIG. 40. THE SERRATED WEEDER.

193. *Weeders* — Small hand tools for use in weeding and thinning such crops as onions, carrots, etc., are of much use, enabling the workman to do the work both better and more rapidly than with the unaided hand. These tools are made in many forms

XXXIV — DRAINAGE.

194. *Importance* — Among the various operations whereby land which is naturally unfit for cultivation can be improved, there is none which exceeds in importance artificial drainage. In nearly all parts of our country are to be found considerable areas either naturally entirely unfit for cultivation on account of the large amount of water present, or producing inferior

crops, because during some part of almost every year they are too wet for the best results. Healthy growth and development of most crops is dependent upon the presence of a considerable depth of soil containing capillary water only. Roots require air as well as water. They cannot find air in sufficient quantity in soils which are too wet. In the climate of the entire eastern portion of the United States drainage of some sort, either natural or artificial, is an absolute necessity. This necessity is explained by the fact that the total amount of water which comes from the clouds in the shape of rains and snow is greater than the total water removed from the soil as a result of evaporation and the demands of growing vegetation. A large proportion of this part of the United States is sufficiently well drained naturally, either because the subsoil is sufficiently open to allow the percolation of the water through natural channels to such depth that it is not injurious, and thence, still through natural channels, into streams and rivers through which it flows to the sea; or it may be that much of the surplus is carried off over the surface where the slopes make this possible. In many cases, however, either because the subsoil is too compact to allow free percolation of water, or because the land lies at a low level, artificial drainage is needed. Low lands often need artificial drainage because they may be flooded: 1, by wash from neighboring higher land; 2, by floods in rivers or streams; or 3 (near the seashore), by the tides. Hillsides and slopes, especially those with compact subsoils, are often too wet: 1, because of springs, or, 2, because of the tendency of the water soaking downward through the soil to work toward the surface as it moves down the slope. Wetness from this cause may be said to be due to *ooze water*, which must be distinguished from water from actual springs, because the methods needed to effect satisfactory relief should be quite different in the two cases.

195. *The portion of the soil water affected by drainage* — It has been pointed out that the water found in soils may be divided into three classes: hydrostatic or ground water, capillary water, and hygroscopic water. We may, of course, also have surface water. One of the first and sometimes the only object of drainage is to carry off this surface water. Of the three kinds of soil water, artificial drainage affects directly only the hydrostatic

or ground water, which, it will be remembered, is that portion of the water of the soil which stands in the spaces between the particles and which is not held by the attraction of those particles (93). By artificial drainage the water-table is reduced to the level of the drains, provided these are sufficiently near together. It must be evident, therefore, that drainage will indirectly affect the amount of capillary water in the surface soil, because such water is always present in largest amounts in the soil just above the water-table, decreasing in quantity as the distance above the water-table increases.

196. *Benefits resulting from drainage* — Among the principal benefits which follow drainage of soils needing it may be mentioned the following: it deepens the soil, promotes aeration, makes manures more effective, warms the soil, lengthens the season both for plant growth and for work, makes all tillage operations easier and improves the tilth, reduces the liability to injury of crops from drouth, promotes the better germination of seeds, results in the production of larger crops of better quality and decreases the risk of failure of crops, reduces the amount of surface wash, makes it possible to haul heavy loads over the fields, produces better sanitary conditions, and decreases the number of mosquitoes and malarial diseases. Thorough drainage and thorough tillage are the main points in land improvement.

197. *Depth of soil* — The roots of most of our farm crops, being restricted to that part of the soil which is above the water-table (94, 98), must develop mainly close to the surface provided the soil is inadequately drained. Wherever the roots go they feed, and it is self-evident that the larger the volume of the mass of soil in which they develop the larger must be the amount of food extracted by root action from the soil particles with which the roots come in contact. As a result of the lowering of the water-table due to drainage the farm is practically enlarged — enlarged downward instead of in surface, for previous to drainage the farmer has not really owned that part of the soil which lay below the usual level of the water-table.

198. *Better aeration* — It must be evident that, so long as water fills the spaces between the particles of soil, air can find its way into it only to a limited extent. As the water-table is lowered the depth to which the air penetrates increases, and the beneficial action of the air in increasing the availability of the natural constituents of the soil is well known (112).

199. *Manure is more effective* — The plant food which is contained in many manures and fertilizers is not in available form when these are applied to the soil. Before it becomes available these manures and fertilizers must, like the soil itself, be exposed to natural agencies, important among which is the oxygen of the air. Moreover, in soils which are well drained the useful micro-organisms, *i. e.*, the microscopic plants which help make the nitrogen of manures available, find conditions favorable for their development; while, if the soil is insufficiently drained, denitrifying organisms, which cause a loss of plant food, multiply (125)

200. *The soil is warmed* — As the amount of water in surface soil is lessened by drainage it warms more quickly, and, since the evaporation is lessened, maintains a higher temperature throughout the growing season than before drainage (109).

201. *The season is lengthened* — Insufficiently drained soil is not fit to work until much later in the season than that which is drained, and as the days become short and the rains more abundant in autumn, the ill-drained soil becomes unfit to work comparatively early. The length of time during which soil can be worked, therefore, is lengthened by drainage, and it is equally true that the length of time during which soil conditions are favorable for plant growth is lengthened.

202. *Tillage* — The soil, when over-wet, cannot be brought into good tilth since neither the plow, the harrow, nor indeed any of the tillage implements will do good work. The preparation of the soil is easier after drainage than before. It crumbles more readily and natural agencies favor the bringing the soil into a mellow and crumbly condition.

203. *Drouth* — At first thought it may seem a paradox to assert that drainage, the process whereby water is removed, lessens the liability of injury to crops from drouth, but no fact connected with the effects of drain-

age is better established. No doubt one of the chief reasons why plants on well-drained soil suffer less in drouth than before drainage is because they are so much more deeply rooted. In soils inadequately drained, the water-table is likely to be comparatively near the surface in the early part of the season. The roots develop accordingly for the most part close to the surface. Later, when rains become infrequent and the weather hot, the water-table falls, the surface soil becomes excessively dry, and the plant whose roots have developed near the surface suffers far more than the one which has sent its roots down deep into the soil. The soil a little distance below the surface will remain comparatively moist and cool (provided a surface mulch is maintained) even in very protracted drouth, and a plant which has its roots in such soil suffers little. Further, the capillary qualities of soils are in general improved by drainage. Especially is this true of the soils containing much clay. A soil with good capillary qualities conducts water from below so that the crop is adequately supplied with water.

204. *Germination of seeds* — Seeds frequently rot in ill-drained soils. For perfect germination a fair amount of moisture, air, and a suitable temperature are essential. These conditions are best met in a well-drained soil containing a fair amount of capillary water. In soil which is over-wet there is not sufficient oxygen and the temperature is likely to be too low for the best germination of seeds.

205. *Crops are larger and of better quality* — The greater depth, more perfect aeration, better tillage, and higher temperature of adequately drained soils, as well as other effects of drainage, make it sufficiently clear why the crops should be larger. They are also of better quality. The proportion of valuable constituents of the different crops, such as starch, sugar, and albuminoids, is greater when the crops have grown upon well-drained soil. Especially is this noticeable in the case of meadows. The superior nutritive value of the grass or hay from well-drained pastures and mowings is well known. In this case the superiority is in part due to the fact that with good drainage the better species of grasses and clovers thrive, while with imperfect drainage those species are apt to be displaced by inferior grasses, sedges, and rushes.

206. *Surface wash* — In the case of fields having considerable slope, when rain falls and finds the surface nearly saturated with water, it flows in large quantities over the surface. With perfect drainage it will more largely soak into the ground, and the amount of wash over the surface with frequent injury through the carrying away of the finer and better particles of the soil and the soluble constituents of manures is lessened.

207. *Sanitary conditions* — The fact that the proximity of ill-drained areas, swamps, and marshes is apt to produce conditions under which malarial diseases prevail is well known. The only perfect remedy for this condition of affairs is the drainage of such areas. This will at the same time greatly reduce the number of mosquitoes, which are now well known to be carriers of certain diseases, among which chills and fever is perhaps one.

208. *Indications of the necessity of drainage* — Any land will be benefited by drainage when any of the following conditions exist : —

1st. If, at any season, water stands for any length of time upon the surface, or comes into the furrow when plowing.

2d. All land in which the water-table during any part of the growing season stands for any considerable length of time within less than three and one-half to four and one-half feet of the surface. Whether this is the case can be determined by digging holes and noticing the height at which the water stands in them.

3d. Any soil which, when left so that natural vegetation can come in (mowings), produces water-loving plants in abundance ; such, for example, as sedges, rushes, and mosses.

4th. Fields having a very compact, clayey subsoil, especially if the surface of the stratum of clay is concave. In such cases there is not a sufficiently free outlet at the bottom for the water which percolates into the soil. Waring says concerning land of this kind : that the surface soil is more or less in the condition of standing in a great water-tight box, with openings to let water in, but with no means for its escape except by evaporation at the surface. Under such conditions the soil invariably soon becomes water-logged.

209. *Kinds of drains* — The methods which have been in use in drain-

ing land exhibit considerable variety, but all may be included under two classes, viz., open ditches and under-drains.

XXXV — OPEN DRAINS.

210. *Uses of open drains* — The open ditch is an effective means of carrying away surface water, and in some situations is useful. It is not, however, adapted to the thorough drainage of land, especially of land which is to be tilled. Some of the chief objections to open ditches as a means of thorough drainage are as follows: —

1st. They take up too much room.

2d. The cost of construction is heavy.

3d. The cost of maintenance is great.

4th. They are less effective than closed drains of the same depth, becoming frequently partially clogged by fine silt which is washed in, and by the growth of water plants and the washing in of rubbish.

211. *Land occupied* — For thorough drainage, ditches must be at least three feet deep. In order to make a ditch of that depth permanent the slope of the bank must be rather flat; the width at the top is, therefore, necessarily considerable. Open ditches three feet in depth, constructed with slopes sufficiently flat to stand, and close enough together to thoroughly drain a field, may easily occupy a quarter of the area of the land drained. Open ditches, moreover, are an obstruction to nearly all the operations of modern farming.

212. *Cost of construction* — Open ditches are more expensive in construction than under-drains of the same depth, for the reason that more earth must be thrown out in order to give the banks the needed slope, and this earth must be spread.

213. *Cost of maintenance* — The open ditch is apt to need frequent cleaning. The sides not infrequently cave, being undermined or thrown down by frosts or the trampling of cattle, while water plants and trash, as well as earth which washes in, tend to gradually fill the ditch.

214. *Where the open ditch is useful* — For reasons which have been briefly outlined it must be evident that open ditches are unsuited for the

thorough drainage of fields. They are, nevertheless, essential for certain purposes, the most important among which are the following: —

1st. To furnish quick outlets for surface water.

2d. To furnish outlets for water collected by under-drains.

3d. As catch-waters on slopes, or at the foot of slopes.

4th. For the partial drainage of both fresh and salt marshes and cranberry bogs.

215. *Construction of open ditches* — The open ditches which are made in marshes, either fresh or salt, or in cranberry bogs, can be cut to considerable depth with perfectly vertical sides. Owing to the peaty character of the soil, the ditch is very permanent, even when so constructed, so long as the water-table is not lowered to so great an extent as to make the surface soil sufficiently dry so that the air will act upon it to a large extent. Should these marshes be thoroughly drained, the water-table being reduced to three or four feet below the surface, then the peaty soil of the banks of the ditch would rot, and caving in would be the consequence. Open ditches in marshes, however, are generally useful, simply in carrying away flood water or the water which comes from the overflow of the tide, and the water-table is not sufficiently reduced so that there is any considerable decay of the peaty soil. When thus partially drained these marshes produce a fair quality of herbage. If it be desired to bring them into English grasses or to fit them for tillage, thorough drainage is essential, in which case the open ditch should not be used. Open ditches, designed as outlets for surface water or to catch and carry off water which comes down from higher levels (catch-waters), must be carefully constructed in order to be permanent, because they are very likely to wash. Curves in such ditches should not be too sharp, for the water, impinging against the outer bank of a ditch having a sharp curve, eats into and undermines the bank, provided it has any considerable velocity.

The grade in the open ditch should be moderate. In average soils it should never exceed six inches in one hundred feet and considerably less than this is ordinarily to be preferred. A fall of two and one-half inches in one hundred feet, with a ditch of moderate depth running full, will give a

current of about five miles an hour. In determining how great a grade will be safe the character of the soil must be carefully considered. In compact clay a greater grade may be employed than in soils consisting chiefly of silt. In deciding what slope the banks of a ditch must have it is necessary to consider both the nature of the soil and the grade. The greater the grade, the flatter must be the slope of the banks of the ditch. In most cases a slope less than an angle of 45° will be unsafe, and in many cases, especially those in which the flow of water is not constant, it is best to make the ditch a very broad, sweeping hollow simply, which can be tilled if need be and planted, and which, accordingly, will offer little obstruction to any of the operations of the farm. Especially is this style of construction desirable and practicable in mowings in which the entire ditch may be grassed and will produce as good crops as any other portion of the field. The permanence of open ditches is always greatly increased by grassing the banks.

XXXVI — UNDER-DRAINS.

216. *Definitions* — An under-drain is a drain which furnishes an underground channel through which water may find its way to a point of discharge known as the outlet. Under-drains offer no obstruction to any farm operations. That portion of the field immediately above them may be plowed, planted, and cultivated just like any other part of the field, and is equally, indeed often more, productive. In every system of under-drainage we may have principal and subordinate drains. To designate these the following terms are in general use : main, submain, and lateral or minor.

In Fig. 41, *a* is the main, *b* the submain, and the unlettered lines indicate the laterals ; *c* is the outlet, which is commonly into an open ditch or natural stream.

217. *Location and functions of main, submain, and laterals.* — *The main drain* must run through the lower portion of the field to be drained. It may be at the foot of a slope in the case of a field sloping principally in one direction, or it may be in the principal hollow running through the field where the latter slopes in different directions. The chief function of the

main is to carry the water brought into it by submains or laterals to some open channel where it is discharged. It may also to some extent draw water direct from the soil adjoining it, provided it is not overloaded with water brought into it by other drains.

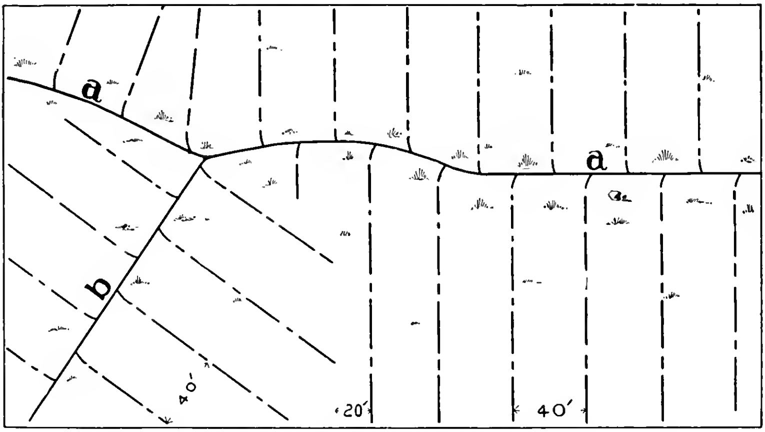


FIG. 41. Plan for Drainage: *a*, the main; *b*, the submain; *c*, the outlet. The unlettered lines indicate the laterals.

The submain will be located, if used at all, which is not always the case, in the secondary hollows, which it will approximately follow. Its chief function is to convey water brought into it by the laterals to the main drain, but it, like the main, may draw water direct from the soil provided it is not already full.

Laterals should generally run approximately at right angles to the main or submain into which they carry their water. They take water directly from the soil and conduct it into the submain or main.

218. *How water enters under-drains* — An under-drain properly constructed will not carry water unless the water-table is above its level. Water does not run directly down through the soil nor percolate through the soil directly into under-drains. Water finding its way downward through the soil, if in excess of what the soil can hold by capillary attraction, will continue to percolate even if it passes below the level of the drains until it reaches the water-table or the great body of hydrostatic water. As per-

colation continues the water-table rises, and when it reaches the level of the drains they will begin to run, but not before.

219. *Kinds of under-drains* — The principal kinds of under-drains which have been employed are the following: Brush, pole, box, stone, and tile drains. Not all of these are of importance at the present time. Indeed, under most conditions, the tile drain is the only kind of under-drain which is worth consideration. Under exceptional circumstances either of the other kinds named may be useful, and therefore each of these kinds will be briefly described. In rare cases land has been drained by means of open passages under ground. Of this type are mole drains made by the use of a special plow. Such drains prove useful only in grass lands with soil of the most compact character and regular grade, for only in such soils could the passage opened by the plow be expected to remain open for any considerable length of time. Such drains have been known to do good work for a number of years in soils of that character, and their cheapness formerly recommended them. Similar unsupported passages through clayey soils were sometimes molded by the far more expensive method of hand labor. Plug drains and wedge and shoulder drains, which were fully described by some earlier writers upon drainage, were of this type. Such drains cannot possibly be recommended at the present time, for when a ditch has been once opened the chief item in the expense of drainage has been met, and to run the risk of the comparatively early failure of the drain in order to save the usually moderate additional cost of putting in something which will be permanent, would be most unwise.

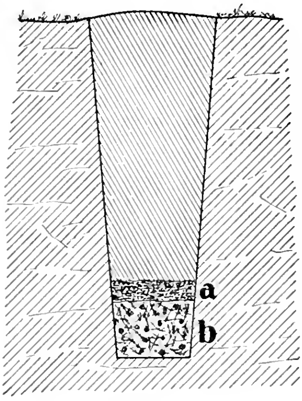


Fig. 42. Section of Brush Drain: *a*, straw covering; *b*, brush.

220. *Brush drains* — Fig. 42 shows a cross-section of a brush drain and the cut needs little explanation. In this drain there is no clear passage for water. It finds its way through the interstices between the brush. The latter is packed in, after the ditch is opened, as closely as may be, covered

with some material such as straw, shavings, seaweed, or sods, which will prevent earth from washing in from above, and then filled and rounded up as shown in the cut in order to provide for settling. Such drains are liable to become obstructed by means of silt or sand which is held by the brush, and, second, the brush will rot within comparatively few years, when the drain becomes entirely useless. Such drains are most serviceable in clay soils because, first, there will be little silt to clog the passages, and, second, the air is largely excluded and the brush will decay less rapidly than in more open soils. Under the best conditions the life of such drains is not likely to be more than about eight or ten years.

221. *Pole drains* — These, like brush drains, may appropriately be called pioneer drains, *i. e.*, drains which may be very useful in a new country where better materials are unavailable. The construction will be understood from the figure. The poles for the construction of drains of this kind should be smooth and as nearly as possible of even size from butt to tip. Chestnut and cedar are among the most durable kinds of lumber available. If the bottom of the ditch on which the poles must be laid is soft, as in mucky soils, or of a treacherous or shifting character, as in quicksands, it will be necessary to lay a slab or board under the poles. Pole drains afford a clear passage for the water, are much less liable to obstruction than brush drains, and are more durable. Under the most favorable conditions such drains might last from twelve to fifteen years.

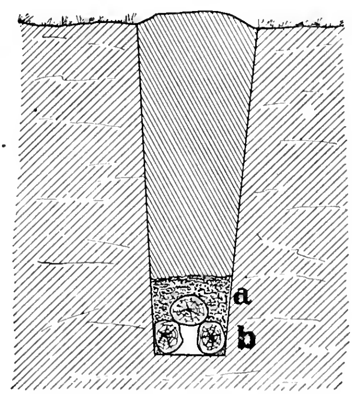


Fig. 43. Section of Pole Drain : *a*, gravel covering; *b*, poles.

222. *Box drains* — In the box drain the passage for water is furnished by a continuous box or trough which is made of boards or plank. These boxes may be made in various forms, two of which are shown in the figure. Whatever the form of the box, provision should be made in its construction for the entrance of water. The most convenient system is to make the

joints at the bottom or lower corners somewhat open by setting short sections of laths between the edges which come together. The box drain with a corner down is more likely to remain free from obstruction than with a flat side down, because when carrying but a small quantity of water this will have sufficient depth to render the lodgment of silt, etc., less likely to take place than would be the case if the same amount of water were spread in a shallow

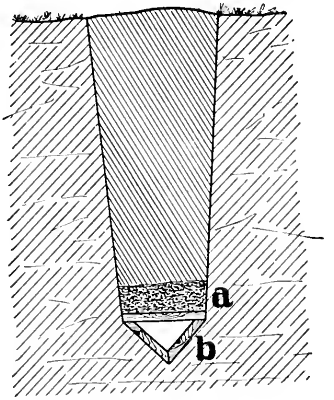


Fig. 44. Section of Box Drain: *a*, gravel covering; *b*, triangular box.

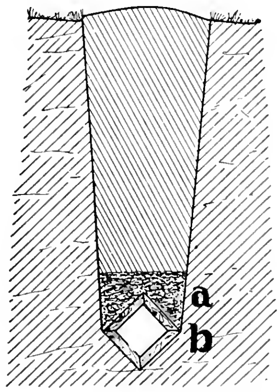


Fig. 45. Section of Box Drain: *a*, gravel covering; *b*, square box set up on a corner.

sheet over a broad, flat bottom. Box drains are less liable to obstruction through entrance of sand or silt than are either brush or pole drains. They are inferior to stone or tile drains, simply because perishable. In most localities they will be found to cost quite as much and often more than tiles of the same capacity.

223. *Stone drains* — Where stones of suitable size and shape are abundant, excellent drains may be made from them, and stone being practically imperishable, these drains, if otherwise equal, are much superior to either pole or box drains. Owing to the irregularity in form of the stones which must usually be used, it is difficult to make a stone drain in such a manner as effectively to keep out the fine earth, which, especially when the drain is new, is likely to wash in. The idea appears to be common that stone drains are cheaper than tile drains. This will not usually be found to be the case. The amount of labor required to make a good stone drain is

much greater than the labor of laying tiles, and labor being taken into account, stone drains can seldom prove cheaper than tile. It, however, sometimes happens that the field needing drainage contains stones which the farmer desires to get rid of. Under these circumstances, in localities where, owing to the cost of transportation, tiles are costly, it may pay to put the stones into drains. It is believed, however, that in most cases they would be found much more useful in the foundation of farm roadways. Stone drains may assume numerous different forms according to the nature

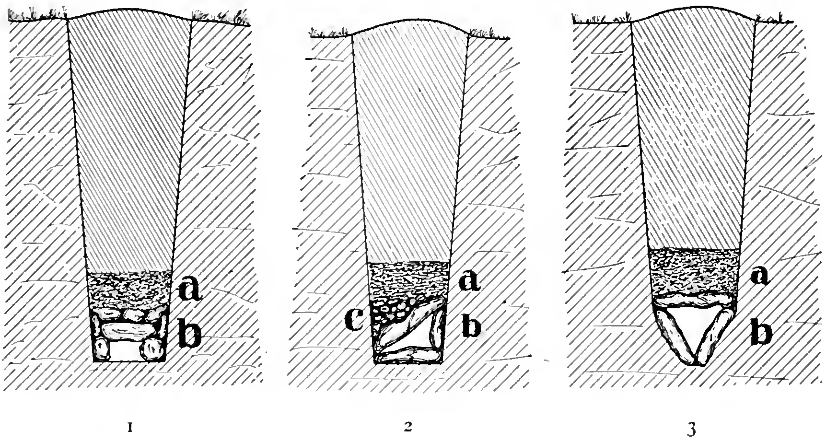


FIG. 46. Stone Drains: 1. *a*, Cobblestone covering; *b*, conduit. 2. *a*, Cobblestone covering; *b*, conduit: *c*, medium stone. 3. *a*, Cobblestone covering; *b*, triangular conduit.

of the stones available and the choice of the maker. Some of the more common forms are shown in the figure. In all those drains represented with an open, regular passage for water, constructed of comparatively large stones, smaller cobblestones are shown above. These are not necessary, although with them the water may reach the drains somewhat more freely and rapidly, especially at first. In most cases where stony land needs drainage, however, there is likely to be a quantity of small stones which must be gotten rid of, and the most convenient method will commonly be to throw them into the ditches above the larger stones which form the conduit. Such stones should not come nearer than about a foot and a half of the surface. The chief danger to stone drains is the liability that silt or fine earth

will wash into them. This is to be guarded against by laying the stones with as close joints as possible. They cannot be laid close enough to keep out the water. The danger is that the cracks will be large enough to allow the admission of earth. Such drains are most lasting in compact soils of a clayey character.

224. *Tile drains* — Drainage by means of tiles specially made for the purpose is practically the only system of thorough under-drainage that can now be advised. Tile drains are better than drains of any other kinds for many reasons, among which the more prominent are the following: —

1st. On account of their regular form a smoother and more uniform conduit for water, and therefore one less liable to obstruction, can be secured than by the use of any other material.

2d. Closer joints can be made than in almost any other kind of under-drain, and therefore there is less probability of the entrance of silt and fine sand.

3d. The material of which tiles are made is durable. Made of good clay and thoroughly burned, tiles, practically speaking, are almost indestructible, provided they are laid below the reach of frosts. The fear that tiles will prove too costly has deterred and doubtless now deters many from undertaking the thorough drainage of land, but the prices at which tiles can be purchased have been greatly reduced within recent times, and are no longer prohibitive.

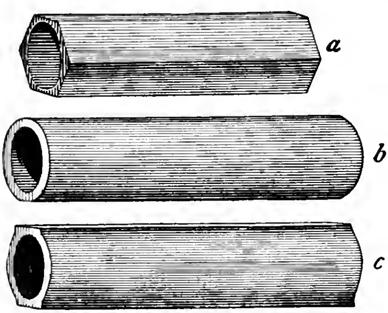


FIG 47: *a*, Six sided tile; *b*, Round tile; *c*, Sole tile.

225. *Kinds of tiles* — At the present time there are practically only about five forms of drain tile in use, viz., the sole tile, double sole tile, the round tile, and the six and eight sided tile. Three of these are shown in the figure. Tiles of each of these forms are made in a number of different sizes. The size is designated by the diameter of the bore, — in the case of tiles with oval bore the greater diameter. The ordinary range of variation is from two to twelve inches, although the round bore tiles are

sometimes made in one and one and one-half inch sizes. The length of land tile is usually a little over one foot, but in buying it is generally prudent to estimate the number of tiles required to be equal to the total length of the drains to be laid in feet, because there are usually some imperfect tiles and breakage.

226. *The best form* — Each of the four forms of tile illustrated has its special merits, and each accordingly has advocates. It is equally true that there are some things which may be said against each of the forms. It seems, therefore, essential to consider the special features of each.

(*a*) *Sole tile* — In favor of the sole tile it is claimed, 1st, that it is easy to lay on account of the flat bottom; 2d, that having an egg-shaped bore with the small end down, it is the best form when the tile is flowing only partly full (which is usually the case), since the depth is greater and the friction less than in any other form. It may be granted that the sole tile stays in place well when laid upon the flat bottom of the ditch, but it is quite as easy to grade a groove in the bottom of a ditch as to grade it flat, for special tools are made for this work (254, *b*). With these grooves the round tiles will remain in place perfectly. It is believed, indeed, that it would generally be found more difficult to lay sole tile than to lay the round or six-sided. The greater difficulty is due to the fact that there are only two possible positions in which these tiles can be laid. Drain tiles, it is true, are molded of perfectly regular form, straight and with ends cut square, but in the process of handling before drying and in the process of burning, not a few of them will become more or less bent, while the ends will seldom be found entirely true and smooth. Under these circumstances, as there is only one possible change in position, viz., turning end for end, it is often found necessary to trim and cut the ends in order to make close joints, whereas with round or six-sided tile, which can be rolled into many different positions, it is commonly possible to make good joints without cutting or trimming. Such tiles, moreover, have greater weight in proportion to their capacity than round and six-sided tiles, which increases the cost of transportation. For the reasons stated therefore, although fine drains may be made from sole tiles, they cannot be so highly recommended as the forms with which they have been compared.

(*b*) *Double sole tiles* — To meet one of the objections against sole tile, viz., that it can be laid only in two possible positions, the double sole tile is made. With a tile of this form four different positions are possible, and the chances of making a good joint without cutting or trimming are increased. Still these tiles are inferior to the forms with which the sole tile has been compared in respect to the facility with which they can be turned to make good joints. These tiles, moreover, are very heavy in proportion to capacity.

(*c*) *Round tiles* — The round appears on many accounts to be the best form. Round tiles can be rapidly laid in the special grooves cut for their reception, and can of course be turned into any position in order to make close joints. In the round tile the bore is of the best form when the tile is full, since there is least friction in proportion to capacity. It is slightly inferior to the inverted, egg-shaped bore of the sole tile when partly full, but the difference is not important. Round tiles, moreover, are the only kind which can be laid with collars (228). These, under some circumstances, are necessary. Their use greatly lessens the danger of displacement of tiles and they would be more frequently used but for the fact that they greatly increase the cost of drainage.

(*d*) *Six and eight sided tiles* — The bore in these tiles is round. The smaller sizes are six-sided, the larger, eight. These tiles have most of the merits of the round tile, and it is claimed for them that they can be laid more rapidly because not liable to roll. From what has been said it will be evident that this point cannot be regarded as of much importance. These tiles cannot be used with collars, but in cases where collars are not needed there is little choice between them and the round. Most of the large manufacturing companies now turn out a large proportion of tiles of this type. It seems to have been received with general favor, being very extensively used, particularly in the West.

227. *Special forms of tiles, for particular uses* — There are a number of special forms of tiles for particular uses, which require brief mention. Among these the most important are curved tiles, enlarging tiles, and junction or branch tiles.

(*a*) *Curves* — These are manufactured with varying degrees of curve, but commonly only in two modifications, viz., first, with a slight curve which changes the direction about half a right angle, and, second, a sharper curve which changes the direction about a right angle. These tiles are commonly designated elbows or simply L's. They are made in all sizes and are useful when it becomes necessary to carry an important drain around a curve.

(*b*) *Enlarging tiles* — The enlarging tile is one which tapers. At one end, for example, it may be three, four, or five inches in diameter, at the other end, one inch less. Such pieces are useful in changing from a smaller to a larger size, on any line of drain. Thus, for example, at the upper end a two-inch tile may be sufficiently large. Farther down, as more water must be carried, a three-inch tile may be none too large. Under such circumstances the work is more secure if an enlarging tile be used.

(*c*) *Junction pieces or branch tiles* — These are tiles of the ordinary construction (and may be of any size) with a short arm or branch, and

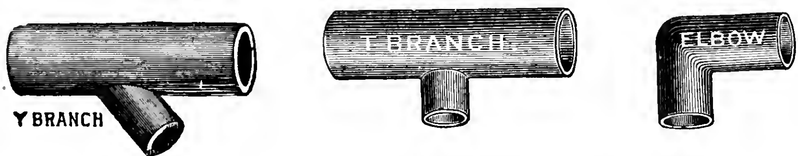


FIG. 48.

they are useful where one line of tiles is to be carried into another. These tiles are made in two styles known respectively as Y's and T's. The Y is generally preferred to the T, because it is better where one drain discharges into another that the water enter the latter with approximately the same direction as the current in the main. If the branch comes in at a right angle a violent eddy is produced at the point of junction which is favorable to the deposit of silt at that point. By the use of the Y the union between a lateral and a main can be made as secure as any part of the drainage system, whereas without Y's deposits of silt, and displacement of tiles at junctions, are common. The size of the short arm varies for tiles of the same size. Thus, for example, we may have a six-inch tile with a short arm or branch either five, four, three, or two inches. To designate the kind wanted in

ordering, use two figures connected by the sign of multiplication, the first figure indicating the size of the tile itself, the second the size of the branch. Thus, Y, 5 x 3, designates a five-inch tile with a three-inch branch; Y, 6 x 4, a six-inch tile with a four-inch branch. The branch in the case of Y's or T's should be either the same size as the lateral which is to be connected or large enough to receive the end of the lateral. It is believed that the latter is usually to be preferred, although when the branch and lateral are of the same size the work is easily made secure if a collar is used where the two come together.

228. *Collars* — Manufacturers of round tiles usually offer for sale short sections for use at the junctions, under the name of collars. Fig. 49. The collar is usually about two to three inches long, and collars are made for

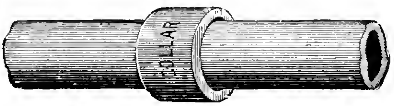


FIG. 49.

each of the smaller sizes of tiles. In ordering, the size of the tile with which they are to be used should be designated. The collar should be of such size as to make rather of a loose fit, since even in the best grades of tile there will be slight irregularities in size and form which would make placing the collars in position altogether too troublesome if the fit should be too close. It is not to be expected that the collar will very materially protect the joint from the entrance of silt. Its use is mainly to preserve the alignment. Collars should be employed only in those cases where there is unusual danger of displacement. They greatly increase the cost of a drain, generally being sold at about two-thirds of the price of the size of tiles with which they are to be used. There is also the added labor of laying, which is considerable.

229. *General conditions affecting the value of tiles* — The quality of the clay, workmanship, the burn, and the presence or absence of glaze very materially affect the value of tiles, and between the product of different manufacturers we find wide variations, as might be expected. Where the clay is imperfectly pugged or molded when too soft, there are sure to be imperfections in the tiles. The product of some manufacturers will be found to contain a considerable number of tiles that are not true in form,

tiles that are flattened, bent, or warped, or tiles with rough ends. It is self-evident that the best drains cannot be made from tiles with these characteristics. The burn is of importance chiefly as affecting the durability. Tiles which are under-burned are soft and likely to crumble. Such tiles when struck with a trowel or hammer give a dull sound, while those which are properly burned give a sharp, ringing sound. On the other hand tiles are sometimes over-burned. Such tiles will be durable but they are commonly under-sized and therefore undesirable. In arranging for the purchase of any considerable quantity of tiles it should be carefully stipulated that all the tiles furnished shall be perfect, and the right to throw out such as are not up to the standard should be reserved. One poor tile in a drain may render the whole drain useless. When drain tiles first came into use it was regarded as essential that the tiles should be porous in order that water might find its way through them. It is now known that this is unimportant. Practically all the water enters at the joints. Some makers of recent years are turning out tiles which are glazed, sometimes inside only, sometimes inside and out. Glazed tiles must be regarded as distinctly superior to those which are not glazed. The inside glazing gives a smoother and harder surface. There is less friction, the water flows with greater velocity and there is consequently less liability to obstruction, while the capacity is increased. Tiles glazed both inside and out must be much more durable than those which are not glazed, as they will be less affected by the agencies which tend to cause disintegration.

XXXVII — POINTS TO BE SETTLED BEFORE THE DRAINS ARE PUT IN.

230. *What these points are* — Whatever the kind of under-drain which is to be put in, there are certain points which should be carefully and definitely settled before the actual work of putting in the drains begins. These points must be so settled in order that the general system may be carefully planned. Unless careful plans are made, the work cannot be done to the best advantage. The points requiring especial attention in planning the drainage of a field are : first, the selection of the outlet or outlets ; second, the exact location of each drain which is to be put in. To determine this

the direction which each drain is to take, the distance between the different drains, and the grade of each drain must be definitely planned. It is evident that in order to arrive at a wise decision upon all these points, the conditions must first be carefully studied, and in all cases where the field or any part of the field is comparatively flat or the area to be improved extensive, a survey with instruments in the hands of an engineer will be necessary.

231. *The survey and study of the conditions* — In New England, where the fields to be drained are often small and with considerable slopes, the survey with instruments may be unnecessary. The drains can be located with sufficient accuracy by the eye, and the grades are sure to be sufficient. In all cases, however, where there is any doubt, an engineer should be called in and a careful survey made. In an improvement involving so great an expense as drainage, it is most unwise to run the risk of unsatisfactory results through hesitation to incur the expense involved in the making of such a survey. Whether such a survey is made or not, a careful study of the conditions extending over a considerable period of time will be of much use in rightly deciding upon the points under consideration. In this study an attempt should be made to determine the underlying cause for the presence of excessive amounts of water. It should be determined whether the water which must be carried away by the drains comes from overflow, from well-defined springs, or from the coming to the surface of ooze working its way through the soil down the slope, or whether the excess of water is due simply to the fact that rainfall exceeds combined percolation, evaporation, and the use of water by the plants in the field itself. Only when the source of the water is known can the drains be most intelligently planned. The study of the conditions, moreover, should embrace observations upon the apparent amount of water to be carried off, and especially the peculiarities of the stream into which the system of drains must discharge. It is highly important to know about the average level of water in this stream as well as the probable frequency and duration of periods when the water is above the average. These points are important for reasons which will be evident from what is said under the next topic.

232. *Outlets* — The outlet is the point where an under-drain discharges

into an open channel ; and the very first thing which will need decision in planning a system of drainage is the position of the outlet. Such channel may be either natural or artificial. It is desirable that at the point where the under-drain discharges it shall be free from obstructions, and that it shall have sufficient depth and grade so that the water in it will not stand above the outlet of the drain. A free discharge from an under-drain is evidently impossible when the water in the channel rises above the mouth of the drain. Should temporary stoppage of the outlet be the only consequence following a rise of water in the channel above the mouth of the drain, the matter might not be serious. It would do no great harm if the water should accumulate in a drain for a few hours or for a day or two to be discharged when the water in the open channel should fall again, if the mischief went no farther. In many cases, however, the water in open channels in time of flood holds suspended large quantities of fine earthy matter, which is likely to settle while the water remains comparatively motionless, thus partially obstructing the drain. Moreover, drains not infrequently carry larger or smaller amounts of silt and, provided the outflow of the water moving through a drain is checked, this drain water stagnates and the silt is likely to settle in the drain. It must be evident, therefore, that if possible the stream into which an under-drain discharges should be such that the water in it will not rise above the mouth of the drain. It will often pay to incur considerable expense in deepening, straightening, and freeing from obstructions in order to lessen the probability that the outflow of water from under-drains will be even temporarily obstructed. For safety, the mouth of the under-drain should be some little distance above the average water level in the open channel. What distance will be necessary is dependent upon the peculiarities of the stream.

233. *Number of outlets* — Most authorities agree that, since the drain is peculiarly liable to accident at the outlet, it is best to so plan the drains as to reduce the number of outlets as much as possible without too greatly increasing the cost. Most drainage engineers, therefore, recommend the use of main drains and perhaps of submains, finally gathering the water col-

lected by many drains, from a large area it may be, into one drain and having only a single outlet into an open channel. Roberts dissents decidedly from this view, holding that it is better to have each collecting drain discharge directly into an open water course. His chief reason appears to be that this system saves cost. It cannot be denied that cost is increased by the use of mains and submains, for the larger sizes of tile are far more expensive than the smaller sizes which answer for the collecting drains. It is not believed that either plan will always be best. Under some circumstances the one, under other circumstances the other, system will give the most satisfactory results. To illustrate the matter, let us suppose that we have a field in which the general lay of the surface is similar to that presented by the open pages of a book opened near the middle so as to be nearly flat and with the bottom of the book slightly lower than the top. Many fields which need drainage have a surface in general similar to these pages, though usually with minor irregularities. There is a low run usually more or less sinuous (in case of the book, straight) running through the middle of the field. In this run there may be a natural stream or, perhaps, an open ditch. Now such a field might be drained in either of the following quite distinct methods: —

1st. The stream or ditch, if there be one, may be improved, some of the sharper turns being made more gradual and the channel deepened and cleared of all obstructions; or if there be no natural stream, then one may be opened. If it be judged that the water level in the course thus improved or opened will be sufficiently below the surface of the land in its immediate vicinity to give each under-drain a free outlet, well above any probable level of the water in the open course, then the cheapest possible method of drainage will be to give each drain, all being run approximately at right angles to the open course, an independent outlet. By this means considerable cost is saved and a moment's examination will enable one to determine whether any given drain is doing its work.

Or, 2d, if it be judged that the water level in any possible course which can be opened through this hollow is likely at times to be so high as to prevent the free discharge of the water by any under-drain, and if, moreover,

the quantity of water which is to be carried is not excessively large, it will be found most satisfactory to put a main drain through this hollow, connecting the laterals which come down from either side with it, thus having but one outlet. This plan has further the important advantage that the obstruction due to an open ditch is avoided.

Or, 3d, it may be that there is a large amount of water sluggishly moving through an open ditch or stream along this hollow, and the level of this water is nearly as high as that of the land on its banks. It may be found that to deepen and straighten this water course sufficiently to carry the water down below the under-drains would be very costly. In such cases it will generally be found best to use two main drains, one on either side of the open water course and a few feet back from it, perhaps 15 or 20, and running nearly parallel with it. These mains can be put down to any desired depth. They may draw some water from the open water course but this will do no harm, although the rule should be to put them sufficiently far back so that not much water will percolate from the stream into them. With these mains, laterals running down the slope should be connected. Each main would have an independent outlet, the field thus requiring two outlets.

In other cases the lowest part of the field may be at one side. We may, for example, have a slope too wet because of the presence of ooze water in the soil. In such a case whether we shall use an under-drain or an open channel at the foot of the slope will be determined by similar considerations to those which have just been presented. Not infrequently a field bordering on a pond or lake requires drainage. In such cases, if the general slope of the field is towards the body of water and fairly uniform, each drain running down the slope may either be given an independent outlet into the pond, or a main drain may be put in running approximately parallel with the margin of the pond and some feet back from it, and into such a main drain the drains coming down the slope may carry their water. Whether the one or the other plan will be preferable will be determined chiefly by the level of the water in the pond or lake. If it is sufficiently low to afford a free outlet for the drains coming down the slope and is not subject to considerable or long continued rise, then each drain should be given an inde-

pendent outlet ; but if the level of the water is permanently or periodically for considerable intervals of time too high, then the other plan will be preferable. It will be evident that, in those cases where the main is put in parallel with the banks of a stream or ditch, or with the shores of a pond in which the water level is high, there will be a strip of imperfectly drained land between the main and the open water course or pond. This, however, is inevitable, whatever the system adopted, unless the water level can be lowered, which would generally involve heavier expenditure than would ordinarily be profitable.

234. *Direction of the drains* — The direction which drains shall take is generally determined by the lay of the land. Main drains, if used, should follow the natural water course, making sweeping and not too abrupt curves. The same is true of submains, which should in general follow the secondary water courses. Laterals should in general run about at right angles with the main or submain with which they are connected. They should, however, be given a little curve just before uniting with the main in order that the water may be carried in obliquely with, and not directly across, the stream in the main. In the majority of instances where land needs drainage the laterals must be given such direction as to secure the greatest possible grade, but in the case of springy hillsides or slopes suffering from ooze water there is opportunity for choice. It is held by some that on these slopes it is better that the laterals run nearly across the slope rather than in any other direction. The reason advanced is that, if they have this direction, they more effectually cut off the water which in general tends to work from springs down the slope. This being the case, it is believed that if the drains run straight down the slope there may be areas between the drains which are not satisfactorily drained. There is considerable foundation for this view. It is, however, believed that in the majority of instances most satisfactory results will be secured by giving the drains an oblique direction down the slope. With this arrangement springs and ooze water are cut off, while at the same time the drain may be given sufficient grade to rapidly carry off the water it collects. The degree of obliquity must be determined with reference to the steepness of the slope. It

should be remembered that it is possible to have too steep a grade in an under-drain (237).

235. *The proper distance between drains* — It is of importance to consider the question of the proper distance between drains with reference almost wholly to the laterals in the system, *i. e.*, with reference to those drains which are depended upon to take the water directly from the soil, and not to carry water which is brought into them by other drains. Thorough examination of the field needing improvement is the first requisite in order to determine what the conditions will demand. There are of course frequent instances in which only portions of a field are too wet. Such inequalities may be due to differences in level, the presence of springs, or the percolation of water at certain points from higher levels. In such instances all that is usually required to put the field in thoroughly satisfactory condition is to put in drains of suitable capacity to take the water from these wet places. This system of arranging drains irregularly, aiming simply to tap those points which are too wet, is sometimes spoken of as the natural system, and in this system a consideration of the question as to the proper distance between the various drains is of no importance, for their location is controlled by unusual conditions, and must be determined by the circumstances in each individual case. In the natural drainage system less drains are required than in the alternative or thorough drainage system, as it is called, in which the laterals are placed at uniform distances. The conditions under which the natural system is most likely to prove satisfactory are more often met with in the Eastern than in the Central and Western states. In the latter states, as well as in many fields in the Eastern states, the thorough drainage system is the only satisfactory one. Where this system is the one used, the question of the proper distance between drains demands careful consideration. The factors chiefly affecting distance are the quantity of water to be carried, depending in considerable measure upon the climate, the depth of the drain, and the nature of the soil. The last two points demand especial attention.

(*a*) *The depth of the drain* — The deeper the drain, within reasonable limits, the greater the distance on either side to which it will lower the water

to a sufficient extent. While the tendency after under-drains are put in is to carry the water-table down to the horizontal level of the drains, it does not, as a matter of fact, usually reach that level because the soil resists the movement of the water. In the immediate vicinity of the drains the water is reduced to their level; but with increased distance from the drains the level of the water becomes higher. The water-table in a soil provided with under-drains is a series of curved surfaces highest midway between the drains. This will be clear from the figure which shows a section of soil which is under-drained. Since the line representing the water-table is always a curve, it is nearest the surface midway between the drains. It follows then that the lower down the drains are, the farther apart they may be without running the risk that the highest point in the water-table midway between the drains will come too near the surface. In this connection it is important to point out that the level of the water-table, under average conditions, must be almost continually subject to fluctuation; rising during storms and falling during the continuance of fair weather.

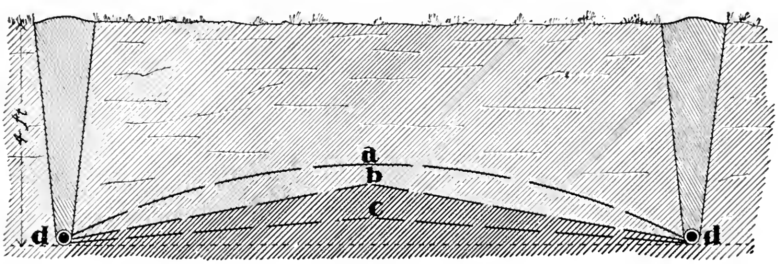


Fig. 50. Section showing water-table in drained soil: *d*, *d*, drains; *a*, *b*, *c*, lines showing water-table under varying conditions.

(*b*) *The nature of the soil* — Soils of an open or porous character allow water to pass through them freely and rapidly. In such soils the curve of the water-table within a short time after storms becomes very flat and the water midway between under-drains can never stand for any great length of time at a level much higher than the level of the drains; accordingly, in soils of this class drains may be placed comparatively wide apart. On the other hand, in compact soils the movement of the water is exceed-

ingly slow and the curve of the water-table has a sharp pitch. After storms it may stand midway between the drains at a considerable distance above their level and it falls very slowly. In such soils, therefore, in order to secure relief from surface water within a reasonable length of time the drains must be comparatively near together. The ordinary range of variation in distance in soils of uniform character is from about 20 feet in the case of the most compact clays to 60 or 70 feet in the case of the more open soils. Under average soil conditions prevailing in the Eastern and Middle states a distance of 40 feet, provided the depth is not less than about 3½ or 4 feet, is commonly regarded as most satisfactory. In the Western states, where the rainfall is somewhat less, the practice is to put the lines at somewhat wider distances than are advised in the East. A distance of as much as 70 or 80 feet with a depth of 3 feet is not uncommon in some of the prairie states. In the compact clays, so common in the subsoils of many of the Eastern states, such distances would be much too great. Waring, one of our best authorities on draining, says in his book on the subject: "In the lighter loams there are many instances of successful application of Professor Mapes' rule that 3-foot drains should be placed 20 feet apart and for each additional foot in depth the distance may be doubled. For instance, 4-foot drains should be 40 feet apart and 5-foot drains 80 feet apart. With reference to the greater distance — 80 feet — this is not to be recommended in stiff clays for any depth of drain." Waring in draining Central Park, New York, put in drains at a nearly uniform distance of 40 feet. The drains averaged about 4 feet in depth and he states that the results are satisfactory. The ordinary range of distance in the Eastern states will commonly lie between about two and three rods where a depth of from 3½ to 4 feet is possible.

236. *Depth of drains* — The depth of drains is in many cases controlled by the peculiarities of the location. The height of the surface of the land to be drained above the level of the water in the final outlet is not infrequently so little that it is impossible or too expensive to obtain what is regarded as the best depth. In such cases one must often be content with a less depth than is known to be essential for the best results. Drains

should in all cases, however, be laid below the range of tillage implements, frosts, and the roots of ordinary crops. The depth reached by tillage implements does not commonly exceed a foot and is often less, though, if subsoiling is contemplated, considerably greater depth is required. The roots of many of our crops penetrate soil which contains capillary water only, to very considerable depths, if it is not too compact. The roots of clover have not infrequently been found at a depth of 6 or 7 feet; those of cabbages have been found even deeper; while parsnips and carrots, in mellow soils free from stagnant water, have been known to send roots to the depth of a dozen feet or more, and alfalfa sometimes goes lower yet. It is clearly practically impossible to place drains deep enough to be beyond the reach of the roots of such crops as these, but the smaller roots, which alone, as a rule, reach these lower levels, will not commonly be found to do any harm. All these crops, except alfalfa, are comparatively short lived; rotation is the rule, and the roots which therefore may grow into the tiles are not likely to become sufficiently numerous to constitute any serious obstruction. The roots of water-loving perennial plants, however, not infrequently penetrate and obstruct drains. Especially is this true of the roots of some of the water-loving trees such as willows, red maples, elm, and ash. The roots of such trees often grow into under-drains and multiply there to such an extent as to completely choke the drain and render it useless. In some cases the growth of the roots has been known to split tiles. There is no practicable method of avoiding injury from such roots and at the same time leaving open joints which are necessary for the entrance of water. If trees which stand nearer a line of drain than a distance equal to the height of the tree cannot be removed, then the best plan is to use sewer pipe in that part of the drain which comes within less than the above named distance of the tree, and to carefully cement the joints. The part of the drain so treated, however, serves simply to carry water which has come into it from above. It cannot take water from the soil. The depth to which frosts will penetrate of course varies widely with the locality as well as with the soil. There is danger that if the frost reaches the drain it will be damaged either by displacement or by the breaking and crumbling of the tiles. Chamber-

lain says, "In the deep, black, porous soils of Iowa with the deep freezing common, 4 feet is none too deep for laterals, and 4½ feet for mains." There are many instances in the Eastern states where drains have continued to do good work for many years and without injury from frosts where the depth is considerably less than that recommended by Chamberlain. It is not believed that in ordinary tillage or grass lands frost is liable to seriously affect drains that are even as near the surface as from 2½ to 3 feet. To some slight extent the depth to which it will be best to drain the land may be affected by the crop. Some crops thrive in soils much cooler and more moist than those which best suit others. Thus, for example, grass will do well in soils in which the water-table is comparatively near the surface. On the other hand, such crops as require high temperatures for their best development do best in more deeply drained soils. Among such crops Indian corn, squashes, and potatoes are prominent. The question of cost also may somewhat affect the decision as to depth of drains. The labor cost increases rapidly with increasing depth. In many soils to cut a ditch 4 feet in depth would cost twice as much as to cut one 3 feet. As has been pointed out, shallow drains comparatively near together may reduce the water-table to a sufficiently low level. If then labor is unusually high, while tiles or other materials for drains are cheap, the expense of drainage may be less for 3-foot drains at, let us say, 25 feet apart, than it would be for one-half the number of 4-foot drains at 50 feet apart. Taking into consideration the prevailing local conditions and the climate of most parts of the New England and the Middle states, it is concluded that under average conditions a depth of from 3½ to 4 feet will be found most satisfactory, although in the case of meadows which it is expected will be kept permanently in grass a depth of 2½ to 3 feet might give fairly good results. In draining soils containing much peaty matter it must not be forgotten that such soils shrink and settle greatly after drainage and that therefore allowance must be made for this in placing the drains lest, after the soil has settled, they be too near the surface (99). In our Western states the practice is somewhat different, drains being commonly placed nearer the surface than has been recommended. Chamberlain states that in the compact clayey

soils of Ohio 30 inches is as deep as the best economy will warrant. In this opinion, however, he is at variance with the best English authorities, who advise placing drains even in clayey soils at from 3½ to 4½ feet, pointing out that while at first the escape of water may be rather slow on account of the impervious nature of the clay, it soon becomes sufficiently porous to permit the water to escape with the necessary rapidity. Waring quotes extensively from a number of English writers all of whom agree that drains, if possible, should be 4 feet deep.

237. *Grade* — The amount of vertical fall in a drain in a given distance is spoken of as the grade or fall. The distance which is most often used in connection with ordinary drainage operations is 100 feet. For example, the statement, "The grade of a field is 5 inches in 100 feet," means that taking any continuous portion of a drain 100 feet in length, the lower end of such a portion is 5 inches below the level of the other end. One thousand feet is sometimes the unit in extensive works. The meaning of such an expression as "30 inches in 1,000 feet" will be readily understood. A drain may be said to have an even grade when the rate of fall is uniform from the upper to the lower end. The grade of drains is in most cases fixed within narrow limits by existing conditions, most important among which are the relative level of water at the outlet and the surface of the field at the farthest point to be drained, and the lay of the surface along the lines which the drains must take. Land needing drainage is often comparatively flat, and but little above the water level at the outlet. The question, then, of chief importance in connection with the grade is usually, "With how little grade will it be safe to lay a drain?" Within ordinary limits, the greater the grade the better. The chief reasons why this is the case are: first, the capacity of a drain of any given size increases as the grade increases, *i. e.*, the drain will carry more water, for the self-evident reason that the water moves through it more rapidly; and, second, because obstruction of the drain is less likely to take place. Any foreign material such as silt is of course less likely to lodge and remain in the drain in proportion as the current of water is more rapid. It is, however, possible that the grade may be too great in any of those kinds of soil which are not of a very compact character. In

the case of a drain having a very steep grade in soil which is liable to wash, tiles are not infrequently displaced. At times when tiles are flowing full, under pressure of a large amount of water above which is seeking an outlet, a portion of the water may be forced out at the joints, and this water, especially when the work is new, tends to wash along the line of the tiles, carrying some earth with it. When this once begins the tendency is to wash more and more, and in the course of time so much earth is carried off that tiles are free to move, under which circumstances the violent flow of water through them often pushes them out of place. Within less than a year after tile drains have been placed on a steep grade in a soil consisting largely of silt or very fine sand, they have been known to move to such an extent that a portion of them have been found standing on end. Of course movement to a degree even much less than this would mean the complete destruction of the drain. This tendency to washing away the earth about the tiles of course differs very widely with the nature of the soil. It is most serious in quicksands. The danger may be in part avoided by the use of gravel or coarse sand for the first few inches of filling, and in very bad cases by the further precaution either to place coarse sand on the bottom of the ditch before putting in the tiles, or by the use of slabs or boards on which the tiles are laid (241, 242). In all such cases, however, it will be safe to give a drain a more moderate grade. The least grade on which farmers can be advised to undertake putting in drains appears to be about 3 inches in 100 feet. With this grade the work must be very accurately executed. With carelessness it may very well happen that the drains in places will be absolutely flat, or perhaps even will slant slightly in the wrong direction. Skilled engineers find it possible to put in drains with much flatter grades. There are examples of successful work with a grade of 2 or 3 inches in 1,000 feet. Such work is possible, however, only when the surveyor's level in the hands of a person accustomed to its use can be employed. The best average grade is believed to range between about 5 and 8 inches in 100 feet. With grades having such an amount of fall a careful workman will have no difficulty in laying drains with sufficient accuracy to do good work. The great est grade which is desirable (although this point has but seldom to be considered) is probably about 10 to 12 inches in 100 feet.

238. *Capacity of tiles or sizes needed* — The amount of water carried by tile of any given size varies with the grade and is of course greater the greater the grade. Tables are often published showing the number of gallons carried by tiles of different sizes at different grades, but such tables can be of no practical use to the farmer, because he does not know the number of gallons of water which must be carried in order to drain any given field and there is no method whereby he can determine this point. It is important, however, to know something concerning the relative capacity of tiles of different sizes, supposing each to be laid on the same grade. In considering this point tiles with round bore only are to be taken up. In the case of tiles with round bore the area of the circle which measures the bore varies with the square of the diameter. It might appear, therefore, that this would be an index to the relative capacity to carry water; that, for example, the 3-inch tile would carry 2¼ times as much water as the 2-inch tile because the square of 3 is 9 and 9 is 2¼ times 4, which is the square of 2. As a matter of fact, however, the 3-inch tile will carry more than 2¼ times as much water as the 2-inch. This is because the amount of friction between the moving water and the tile is relatively greater in the smaller sizes. Taking friction into account, according to Wheeler, tiles of different sizes have about the following relative capacity to carry water, as compared with the 2-inch tile taken as a basis of comparison:—

2½-inch tile carry 1.5 times the water carried by 2-inch tile.

3-inch tile carry 2.5 times the water carried by 2-inch tile.

4-inch tile carry 5 times the water carried by 2-inch tile.

5-inch tile carry 7.5 times the water carried by 2-inch tile.

6-inch tile carry 12.5 times the water carried by 2-inch tile.

8-inch tile carry 25 times the water carried by 2-inch tile.

(*a*) *Size for laterals* — It is the general practice throughout the Eastern states, when land is thoroughly drained by means of drains placed at equal distances apart, to use 2-inch tiles for all laterals. In the Middle and Western states larger tile are, as a rule, employed. Speaking of the size required in laterals, Chamberlain says: "The tendency toward larger size, especially in the rather level prairies in the West, is manifest and wise.

The soil is more porous, and hence laterals may be much farther apart and wisely laid deeper (even 4 or 4½ feet) than in our more compact, clayey soils in Ohio. Also, as the grades there are less, the sizes must be larger. The manufacture of 1 and 1½ inch tiles has long been discontinued, even in Ohio, and few 2-inch tiles are now made in some sections though they are large enough for an outlet for one acre with good grade. But in Illinois 3 and 4 inch tiles are now the smallest sizes found at most tile kilns. The material is not expensive and the tendency toward large sizes is wise, except where freights or long hauling make the weight important."

(*b*) *Size needed for mains* — Wheeler, who is good authority on drainage practice in the Eastern states, says that on soils of open character with grades not flatter than 3 or 4 inches, the 2-inch main will carry all the water collected by the drains necessary in an acre of such land about as fast as it can find its way into them, and he considers this size of main sufficient for an acre of such land. For compact clays he considers a 2-inch main sufficiently large for two acres, since in soils of this character a smaller proportion of the water percolates through the soil to the drains, and that which finds its way to them reaches them much more slowly than in case of more open soils. If the fall be 6 inches in 100 feet, the 2-inch main will carry water from 1½ times the above named areas, and, with a fall of 12 inches in 100 feet, it will carry the water of double the above named areas. The same authority says that for the more open soils a 4-inch main would carry the water from 5 acres, a 6-inch main the water from 12 acres, and an 8-inch main the water from 25 acres, provided the fall is from 3 to 4 inches. If the fall is 6 inches, the different sizes will carry the water from 1½ times the above named areas. In clay soils the number of acres for the different sizes at different grades will be double those above named.

Waring gives the following rules for the size of mains when the fall is 3 inches in 100 feet :—

1¼-inch tile, 2 acres.
2¼-inch tile, 8 acres.
3½-inch tile, 20 acres.
Two 3½-inch tile, 40 acres.

6-inch tile, 50 acres.

8-inch tile, 100 acres.

In commenting upon this statement as to sizes needed, Waring says: "It is not pretended that these drains will immediately remove all the water of the heaviest storms, but they will always remove it fast enough for all practical purposes, and if the pipes are securely laid the drains will only be benefited by the occasional cleaning they will receive when running 'more than full.'" All authorities agree that it is a mistake, whether for laterals or for mains, to use tiles larger than are really necessary. Not only does this involve greater expenditure, for the prices of tiles increase rapidly with the size, but it makes a drain more liable to obstruction than a smaller one, since silt is much more likely to settle in large tiles in which the quantity of water ordinarily flowing would be sufficient to give a stream of but little depth. The flushing of a drain under pressure of a great volume of water which is endeavoring to force its way into it is very beneficial. Chamberlain has given rules for the size of mains in tile drainage which appear to be worth stating. According to his rule, in order to determine the number of acres that can be drained by means of different sizes, the diameter of the tile should be squared, and the result divided by 4 when the grade is not more than 3 inches in 100 feet. On this basis it will be found that: —

A 3-inch main will drain 2¼ acres.

A 4-inch main will drain 4 acres.

A 5-inch main will drain 6¼ acres.

A 6-inch main will drain 9 acres.

When the grade exceeds 3 inches in 100 feet, the diameter should be squared, and the result divided by 3. On this basis the number of acres provided for by means of different sizes would be: —

3-inch, 3 acres.

4-inch, 5⅓ acres.

5-inch, 8⅓ acres.

6-inch, 12 acres.

8-inch, 21⅓ acres.

It will be seen that the results of the application of Chamberlain's rule

for grades slightly exceeding 3 inches agree closely with Wheeler's estimate as to the capacity of the different sizes. It is believed that the use of such sizes as are recommended by Wheeler and Chamberlain will be found safer than the selection of such sizes as are recommended by Waring.

XXXVIII—PRACTICAL SUGGESTIONS.

239. *Planning the work* — In those cases where an engineer is not employed and the farmer must plan the drains and see that they are put in right, the following suggestions may be of value: The first thing to be done is to make a careful examination and find the best outlet for each drain or for the single outlet of the main, if a main is to be used. Second, if a main is to be used, find the highest point which will be reached by it and determine the difference in level between the outlet and this point. Third, find the highest point which is to be reached by any of the laterals and the difference in level between this point and the point where the lateral either unites with the main or discharges into an open water course. Fourth, drive stakes at distances of 100 feet apart along each line where there is to be a drain. Having carefully determined the location and the grade of each of the drains which are to be used, preparations must be made which will enable the workmen to open the ditches to exactly the right depth and to give an even grade with the rate of fall determined upon. The system followed may be the same for each line of drains and this part of the work should be most carefully done, because the efficiency of the drains depends so largely upon an even and accurate grade.

240. *Method to be followed in securing the proper grade* — The depth of the drain at the mouth is always determined by the natural conditions, and in preparation for grading the best system for the farmer to follow appears to be to drive straight stakes on either side of the proposed ditch at the mouth, the tops of which after being driven enough to be firm should be a little more than six feet above the level of the drain at the lower end. When these sticks are in place take a narrow strip of light board and nail it firmly to the stakes (being careful to have the upper edge horizontal) at such a height on the stakes that the measurement from the upper edge of

this horizontal batter board to the bottom of the ditch when it is at the right depth will be exactly six feet. Next, go to the upper end of the drain and set a similar pair of stakes with batter board. The height of this batter board also should be exactly six feet above the bottom of the ditch when it is at the right depth, and the depth at this point will be determined by the grade which the drain is to have. Thus, for example, if the line of drain is 500 feet long and the calculated grade is 5 inches in 100 feet, then the batter board at the upper end should be 25 inches higher than that at the lower. A measurement of six feet from the upper edge of this batter board will give the proper level at the upper end of the drain. Having in this way established points, by measuring from which the right depth at the lower and upper ends can be determined, similar pairs of stakes of sufficient length and size so that they may be firmly driven should be set, one on either side, at intervals of about fifty or sixty feet along the line of the drain. Two men then, working together, can place batter boards on each pair of stakes One man should stand either at the upper or lower batter board and, sighting to the other, should determine the point at which the batter board should be set on each of the pair of stakes. When this has been done a light stout cord resting on the tops of the batter boards directly over what is to be the center of the drain should be stretched perfectly taut. Since it will not answer to pull upon the batter boards to any considerable extent, it will be best to drive a single stake firmly into the ground behind both the upper and the lower batter boards, to which the cord can be fastened. These stakes should be firmly braced. The cord having been accurately stretched and the batter boards carefully set, it will be understood that we have thus established a line directly over the middle of the drain which has the exact grade the drain should have. It then only remains for the workmen in finishing the ditch to be sure that they dig throughout the entire length to a point exactly six feet below the cord above. This work of finally grading the ditch should be done by the farmer himself or by some intelligent and very careful workman. To facilitate the work, whoever does the grading should be provided with a measuring rod, and in testing the depth of the ditch he should be careful to

hold this rod vertical. It is evident that accurate work depends upon having the cord taut and on a true grade. Too much care, therefore, cannot be used in putting up the batter boards and stretching the cord; and it should be remembered that exposure to varying weather causes the cord to shrink in damp and to relax in dry weather as does a clothesline. This will make it necessary to restretch the cord whenever measurements are to be taken. For this reason, and also because there may be some danger that stakes may be disturbed during the progress of the work, it will usually be best to open the ditch nearly down to the grade before setting the batter boards and stretching the cord. The ordinary workmen of the farm may be allowed to do this work but great care should be taken that they do not dig too deep at any point, for it is highly necessary that tiles be laid on an undisturbed bottom as firm as possible. Each line of drain may be graded in the same manner, but wherever the slope is considerable it may be unnecessary to follow this system. In many fields in the Eastern and Middle states a careful workman can grade a ditch with sufficient accuracy by the eye and by watching the flow of water which comes into the ditch as it is opened. It must further be pointed out that if the grade changes on any single line it will be necessary in setting the batter boards to make proper provision for such change. Numerous other methods of testing the accuracy of grades in drainage operations are in use. In many of these, devices which can be easily homemade are employed. Among these the walking level, the T level, and various combinations employing the spirit-level are common.

241. *Digging the ditches* — This is the most expensive item in connection with under-drainage and the cost of the operation will be very largely determined by the manner in which this work is done. In case the soil is fairly uniform in character, not too compact, and free from large stones, the use of a plow is attended with considerable advantages. A deep, wide furrow is turned out by the ordinary plow, then a second furrow by means of a trench plow. It may not be possible to throw out all the earth loosened by these plows, but even if that is not the case the breaking up and mellowing of the soil will enable the workmen to make more

rapid progress. Chamberlain makes the statement that he, with two men to help him, in one day laid fifty rods of tile drains, opening the ditch (which had first been plowed as above), putting the tile in place and filling, thus entirely completing the work, the depth being three feet. At this rate of progress the cost of tile draining would be very moderate. So rapid work would not as a rule be possible in the common compact and often more or less stony soils of the Eastern states. It will in many cases be cheapest to have the ditches opened nearly down to the grade by contract; the grading, however, should not as a rule be left to contract labor. When the work is to be done by day labor the following suggestions will, it is believed, be found helpful: —

1st. Find men for the work, if possible, who are accustomed to it.

2d. Have them open narrow ditches. About 20 inches in width at the top and 5 at the bottom will be suitable for laterals of average depth.

3d. Teach the men to place the earth on the edge of the ditch and to get the shovel back to the bottom as soon as possible. Do not allow them to throw the earth.

4th. Cut with a corner of the shovel, not with the whole width of the blade.

5th. In most cases allow the workmen to use the tools to which they are accustomed in preference to those which may be theoretically better but to which the workmen are not accustomed.

6th. In whatever manner the work of opening the ditches may be done it is generally best to begin to work at the outlet in order that water as it enters may have opportunity to escape.

242. *How tiles should be laid* — In laying tiles it is generally best to begin at the lower end, because closer joints are likely to be made than when they are laid beginning at the upper end. If, however, there is any great amount of water flowing through the ditch it may be best to begin at the upper end, using great care to crowd the tiles as close together as possible. Should tiles be laid from the lower end, there is danger, in case much water is flowing in the ditch, that it will carry earth with it into the tiles, and if the grade be comparatively flat it is likely that the earth will

settle in the tiles, thus partially obstructing them. Before beginning to place the tiles in the ditch it is best to string them along on the bank within reach of the man standing in the ditch, taking care to discard all imperfect tiles. In putting the tiles in position in the ditch make as close joints as possible. Joints cannot be made close enough to exclude water. The danger is that cracks will be left of such size that silt or fine sand will be carried into the drain. The joints should be covered with muslin, tarred paper, sod, or clean, coarse sand. This covering is necessary in order, so far as possible, to prevent fine earth washing into the drain while it is new. Neither the cloth, paper, nor sod will last many years, but after the work is settled there is comparatively little danger that silt will enter the tiles. If it be found that there is quicksand in the bottom of the ditch, or that the bottom is soft and insecure, it is best to lay the tiles on a board, in which case they may be kept from rolling sideways by means of laths. Tiles should be laid almost immediately after the ditch is graded. It is unsafe to wait, because water naturally flowing through the open ditch or a storm may lead to such an amount of washing as to destroy the grade. It should be remembered that the efficiency and durability of the drain depend almost entirely upon careful laying and true grade. Careless laying may mean the entire loss of the work. If it be necessary from any cause to lay tiles upon a curve, either the special forms designed for use on curves should be employed (227, *a*) or the inner side of the tiles should be chipped off with a trowel or hatchet in order that close joints may be made. It will not answer to lay square-ended tiles on curves, for the open joints on the outer side of the curve will permit the entrance of too much earth. When the system includes both mains and laterals it will be necessary to put in the branch tiles for the lateral as the work on the main progresses, and to prevent the washing in of earth the short arm of the Y should be closed by use of a wisp of straw, a brick, or flat stone. In placing the Y's in position use care that the short arm of the Y is raised a little above the center of the main. If this is not done there may be danger of water backing from the main into the lower end of the lateral.

243. *Filling the ditch* — A workman should closely follow the man who

lays the tile, and as each joint is covered with muslin, paper, or other material, this workman should carefully throw down a shovelful of earth, which the man laying the tile should crowd firmly about the joint in order to hold all in place. In addition to doing this work, the man on the bank should continue the filling as far as possible, taking care in throwing in the earth not to disturb the tiles, and being careful further not to throw in large stones which might break the tiles. In the course of filling it is desirable that the earth be packed down as solid as may be one or more times during the operation. Even if this be done it will be found that the earth removed from the ditch, on being put back, makes it more than full. It should, nevertheless, all be placed above the ditch, this being considerably rounded up when the work is left. This rounding up of the work as shown in the cut is necessary in order to provide for the settling which always follows. Should the line above the tiles become lower than the adjacent land, there would be great danger that water washing into this hollow would find crevices in the freshly filled earth through which it would begin to run down directly into the tiles. Should this happen, earth is sure to be carried into them, and the obstruction of the tiles, and perhaps serious displacement, follow. The work of filling is sometimes entirely done by hand, shovels as well as heavy hooks and hoes being employed according to the taste of the workman. In many cases, provided the field undergoing improvement has a soil sufficiently firm to allow it, considerable saving may be made by employing implements drawn by horses or oxen. Both common and special filling plows, ordinary scrapers and road scrapers have been employed. In some cases a wide scraper specially made for the purpose in form of a letter V, with the sharp end cut off, has been found to do good work. Such a scraper may be made of two planks about 12 feet in length, firmly fastened together, with the forward ends about 6 feet apart and the rear ends 2 feet or less apart. Such

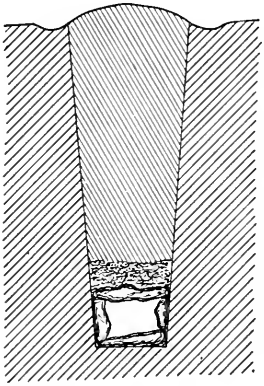


FIG. 51. The completed drain, showing the rounded top.

a scraper drawn by a pair of horses with wide hitch, one walking on either side of the ditch, may do excellent work, if the earth which is to be filled into the ditch has not become too compact, and if it has been thrown out in about equal quantities on the two sides. Some writers on drainage recommend that in digging ditches for under-drains, surface soil should be thrown on one side and subsoil on the other. It is not believed that it is at all essential to take these precautions, for it is found that even during the first few years after under-drains are put in the crops immediately above the drain are quite as good as on either side, even although in filling the surface soil may have been largely put in at the bottom. If, however, in the course of digging, earth of different grades of fineness should be found, it will pay to keep the coarsest grade of earth by itself, because if such earth can be filled in immediately above and about the tiles, the danger from washing in of silt is greatly reduced. Recognizing the fact that obstruction of tiles through washing in of silt, especially where the grades are flat, not infrequently occurs during the first few years after drains are put in, it is recommended that, in soils which are of the nature of quicksand, or which consist chiefly of silt and excessively fine sand, coarse sand or gravel be used in filling the first few inches above the bottom of the ditch. The use of sand or gravel in this way must always considerably increase the cost of putting in drains, and it should accordingly be resorted to only when circumstances seem to render it absolutely essential.

244. *Silt-basins and peep-holes* — Silt-basins and peep-holes are practically wells, the bottoms of which extend a little below the level of the tile or other under-drain. Such wells may serve two useful purposes: first, they make it possible for the farmer to determine whether the drains are working properly; second, they serve as a trap for the collection of silt. The term silt-basin is commonly applied to such wells as are of considerable size. The term peep-hole is generally used to designate wells of small diameter put in chiefly with the object of making it possible to determine whether drains are working properly. The peep-hole is not large enough to prove of much use in retaining silt. The cut shows a silt-basin of approved construction, brick being employed in the bottom, and tile above.

All joints should be carefully cemented, and it is believed, although this is not always done, that it will be expedient in all except soils of the most compact character to use a flat stone at the bottom and to cement the joint between the bottom and the first course of bricks. It has been found that earth not infrequently washes into silt-wells, finding its way with water through the joints or under the bottom of the wall. Joints must be close to prevent this. In some cases silt-wells are brought to the surface, where they are provided with a stout cover. Wells coming to the surface are very liable to breakage through accident, especially in fields which are plowed, and it is believed to be best to carry the well to a point not nearer the surface than about 20 inches. A stout cover, which should be either of stone or cast iron, should be employed, the earth being filled in above the well as shown in the cut. The bottom of the well should be several inches lower than the outgoing tile, and the latter in turn should be about two inches lower than the tile or tiles which bring water into the well. The diameter of the well may vary according to the amount of water coming into it. In most cases a well of about a foot to fifteen inches in diameter will be large enough. The water which is brought by the drains into such a well comes to partial rest, and silt or fine sand which it carries will largely settle and remain in the well, from which it must from time to time be removed. Peep-holes are commonly made by setting Akron tile or iron pipe on end. If these, for convenience of inspection without the trouble of digging, are to be brought to the surface, they should extend far enough above the ground to be easily seen. Care should be taken, as in the case of silt-wells, to make tight joints both at the bottom and between tiles, in order to

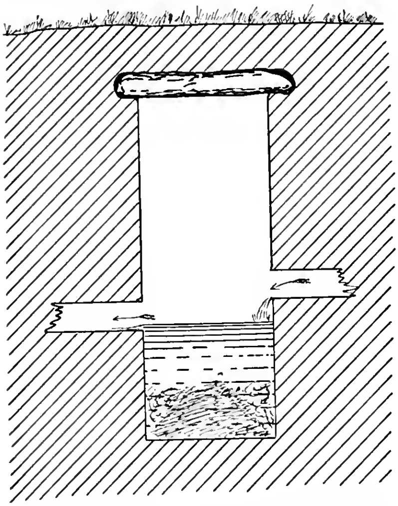


Fig. 52. Silt-Basin and Peep-Hole. Arrows indicate the course of the water through the drain, with the well below and the opening at the top of the shaft.

prevent the washing in of earth. The cut shows a peep-hole of approved construction. There is considerable difference of opinion as to the number of silt-wells and peep-holes which should be put in. It is, however, evident that their use must increase the cost of drainage and it is not believed that they should be much employed. They will be needed, if at all, at such points as the following : —

(*a*) On an important drain at a point where the grade becomes more flat.

(*b*) At the junction of important lines of drains.

In the case of small drainage operations where each drain is given an independent outlet into an open water-course, silt-basins and peep-holes are unnecessary.

XXXIX — OBSTRUCTIONS IN DRAINS.

245. *Chief causes of obstructions* — The chief causes which lead to the obstruction of under-drains, several of which have been alluded to in telling how drains should be put in, are : filling with earth, choking with roots, the displacement of tiles, the formation of a coat of insoluble oxid of iron inside the tiles, and the entrance of animals.

246. *Filling with earth* — The chief causes of filling with earth are defective grading and laying. If the grades are even, if good, smooth tiles are employed, and the joints close and carefully covered with muslin or paper (242), there will be comparatively little danger of filling. When, however, grades are comparatively flat, and in soils consisting largely of silt, there is considerable danger of obstruction from this cause, especially during the first year or two. After the earth has become fairly settled about the tiles there is little danger of obstruction from this cause.

247. *Filling by roots* — In discussing the proper depth of tiles (236) this danger has been fully considered and the remedies pointed out. These, it will be remembered, consist either, first, in the removal of the tree, or, second, using glazed tile and cementing the joints within any distance from the tree less than its height.

248. *The displacement of tiles* — Tiles if too near the surface may be dis-

placed by frosts. This is more apt to occur if by reason of the nature of the strata, the grade, or any other condition, one end of the tile is in soil of a different character from that about the other. The action of frost under these conditions may easily throw the tiles out of line, and will in time perhaps stand them on end. Among other causes of displacement are difference in degree of hardness of the bed on which the tile is laid (allowing the tile perhaps to settle at one end or allowing a part of the tiles to settle), carelessness in filling, and occasionally the burrowing of animals.

249. *Formation of a coat of iron-rust* — Iron is found in most soils and often in considerable quantity. Where drains have flat grades a coat of iron-rust may gradually form on the inside of tiles. This iron-rust forms a rough coat, which decreases the capacity of the tile to carry water and increases the danger that silt or any other foreign matter carried along by the water will lodge and thus gradually block the flow.

250. *Animals sometimes enter drains* — Small water animals such as rats, muskrats and frogs, sometimes enter drains at their outlets at times when comparatively little water is being discharged, and such animals have been known to work up through the drains to points from which they have found it impossible to return and their dead bodies have sometimes been found blocking a drain. Obstruction from this cause can easily be prevented by covering the tile at the mouth with a grating. Such gratings in most cases become gradually obstructed through accumulation of fibers of roots, iron-rust, etc., and must sometimes be removed and cleaned.

251. *Signs of obstructions* — The most obvious sign that a drain is obstructed is the gradual return of the land to its original condition. In the neighborhood of an obstruction and above it the soil will gradually become wet and soft, while below the obstruction it will still be well drained. Having found the apparent place, take a crowbar or spade and make several holes along the line of the tile. The comparative level of the water in these holes will indicate very nearly the place of the obstruction.

252. *Removal of obstructions* — When a drain is but partially obstructed such obstruction may sometimes be removed by flushing. To flush a drain through which some water is still flowing it is only necessary to stop the drain at the outlet for a considerable length of time. Under these circum-

stances the drain and the soil about and above it are soon entirely filled with water, and on opening at the mouth the rapid outflow of this water under considerable head will often thoroughly cleanse the tiles. If the tile is wholly closed it will be necessary to dig down to it and remove the obstruction in such manner as circumstances may render necessary. If the obstruction extends but a short distance and there is considerable water it can sometimes be started by the use of a pole, when the water will carry the foreign material out. If the obstruction is complete and extends for a considerable length the only way in which it can be removed is by taking up the tiles. This also would be the only way in case tiles were obstructed by living roots.

253. *Cost of under-drainage* — As with other farm operations, conditions are so variable in different fields and in different localities that no one price can be given which will apply to all conditions. On the College farm at Amherst, Mass., it has been found that to thoroughly drain fields of medium, compact soil with laterals from 35 to 40 feet apart, and about 3½ feet deep, costs about $50 per acre. It is impossible to do work as cheaply in a State institution as it can be done under private management. There are, however, very few recorded facts pertaining to the cost of drainage in the Eastern states. Chamberlain gives the actual cost of draining fifteen acres at $21.57 an acre. English writers estimate the cost of thorough drainage at about $25.00 an acre. The important items making up the cost are: opening the ditches, cost of tile, and cost of labor in laying and filling.

(*a*) *Opening the ditches* — The cost of opening ditches will vary greatly with the nature of the soil and the depth (236). It is also affected in marked degree by the experience and skill of the workmen. If the work be done by contract in the Eastern states the price for digging ditches averaging about 3⅓ to 4 feet may vary between twenty-five and seventy cents per rod.

(*b*) *Cost of tile* — The cost of the tile will vary widely in different localities, being chiefly affected by the distance from the point of manufacture. It will require about one thousand pieces of 2-inch tile, according to the system of under-drainage generally followed in the Eastern states, to lay

the laterals considered necessary in an acre, and these in most localities will cost about $10. The cost of tiles increases rapidly with the diameter, as illustrated by the following price-list sent out by a large manufacturer. The prices are for round tile, but as a rule the prices for six and eight sided tiles are about the same: —

2-inch tile, per thousand,	$15.00
2½ inch tile, per thousand,	20.00
3-inch tile, per thousand,	25.00
4-inch tile, per thousand,	45.00
5-inch tile, per thousand,	75.00
6-inch tile, per thousand,	100.00
8-inch tile, per thousand,	150.00
12-inch tile, per thousand,	350.00.

Prices as published in lists similar to the above are always subject to large discounts, in most cases in the neighborhood of forty per cent.

(*c*) *Laying and filling* — The cost of laying and filling will not, it is believed, generally exceed about ten cents per rod, provided the best means for doing the work are employed, although of course the cost of these operations as well as of others is subject to some variation. With a large amount of water flowing through the ditches it costs more to lay tiles well than in ditches where there is little or no water, and to fill is more costly in proportion as the ditch is deep and the soil compact and adhesive.

254. *Drainage implements* — (*a*) Machines. A number of different styles of steam or horse power ditchers are manufactured for use in underdrainage, and there is one machine by use of which it is proposed both to open the ditch and to lay the tiles. It is not believed that the latter machine is a success, but under some circumstances machines may be used with advantage in opening the ditches. All necessarily require great power, and their use is not practicable except in large fields with even surface and in soils free from stones. In addition to machines designed to open the ditch there is another type which aims simply to loosen the earth, somewhat as a pick might do. One of these machines is shown in Fig. 53. It is not believed that the use of machinery will, as a rule, be found profitable under the conditions prevailing in the Eastern states.

(*b*) *Hand-tools* — There is some diversity of opinion in regard to the selection of tools for use in ditching, some preferring special ditching tools while others advocate the use of ordinary picks, shovels, and spades. The special ditching spades and tools shown in Fig. 54 are designed for use in

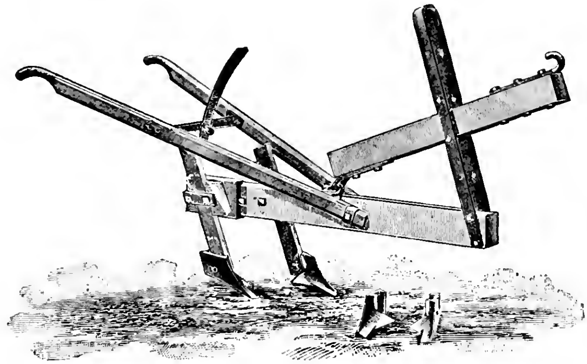


Fig. 53. Ditching Plow.

opening very narrow trenches,—the width at the bottom only slightly exceeds the diameter of the tiles to be used. The wider spades are of course to be used at the top, the narrower in the bottom, of the trench. It is not possible for workmen using these tools to stand in the bottom of the ditch. The last spade is used in removing a cut below the level on which the workman stands and the bottom of the ditch must be finished by the use of the long-handled crummer, also shown in the cut. When the ditch is opened only the width of these very narrow implements, it is evident that the workman cannot stand in the ditch to lay the tiles, and the special pipelayer, also shown in the cut, is employed in putting them in place. Skilled workmen accustomed to these tools are able to put in drains very rapidly and cheaply by their use, but it is not believed that the comparatively inexperienced workmen (as a rule the only kind that can be employed in this country) should attempt to do the work in this way. There is grave risk that perfect joints between tiles would not be made, and the workmen, being unaccustomed to the constrained and somewhat unnatural position which the use of these implements requires, would probably not open as great a length

of ditch in a day as with ordinary spades and shovels; and, in case of hard soils, the pick with which the earth is first loosened. With inexperienced workmen, ditches of just sufficient width to stand in comfortably should be the rule. In grading the bottom of the ditch for the reception of round tiles it will, however, be found expedient to cut a half round groove, as shown in the cut Fig. 55, by the use of the special implement designed for the purpose, which is also shown in Fig. 54, No. 6.

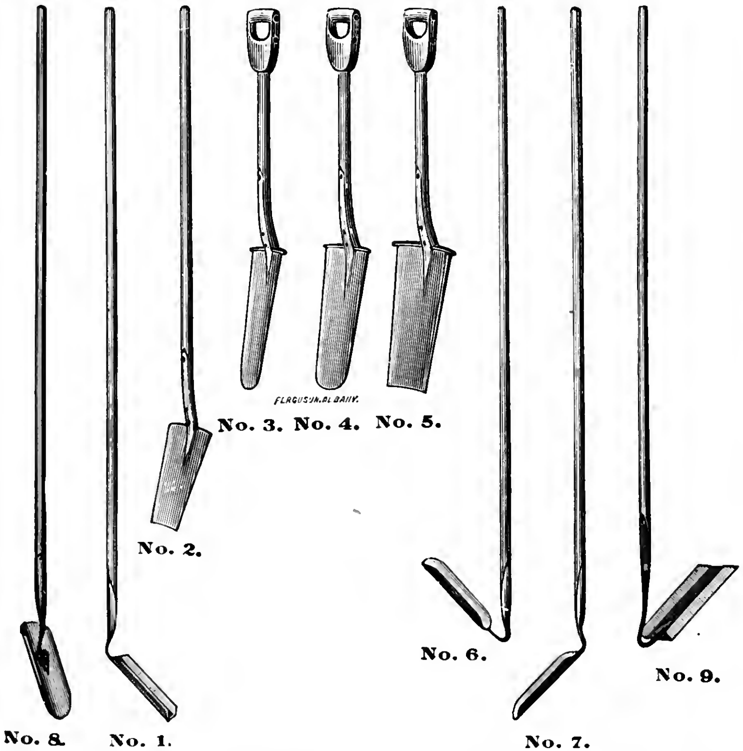


FIG. 54. HAND TOOLS FOR USE IN MAKING DRAINS. Nos. 3, 4 and 5 are used in digging the ditch; Nos. 6, 7 and 9, for cleaning and making groove at bottom of ditch for round tile; Nos. 1 and 8, for cleaning and leveling bottom of ditch for sole tile; No. 2, for shoveling out loose dirt and leveling bottom of ditch.

255. *Make a plan of the field drained* — A plan showing the location of all under-drains put in is almost sure to prove useful. It is surprising in how short a time all surface indications that a drain is working below disappear. Almost every one, when putting in under-drains, believes that he

will always remember just where each is put, but this can seldom be depended upon, and even were the individual memory reliable, later owners or occupants will need the guidance of a plan. In any system it may sometimes be necessary to dig up drains for the removal of obstructions or repairs, and when this is the case the plan will save much labor in finding the drains. A sketch plan, provided a few distances from some fixed and permanent natural object are given and distances between drains indicated, will answer, though a plan drawn to scale is somewhat more satisfactory.

XL—IRRIGATION.

256. *Definition*—Irrigation is the practice of artificially supplying water to land for the purpose of furnishing moisture and plant food. In some cases one, and in others the other, of these two objects is more important.

257. *A bit of history*—The first definite record concerning irrigation gives an account of the construction of the pools of Bethlehem-Etam by Solomon. The water was conducted to the eastern slope of Mount Zion by a 10-inch earthen pipe and the system was reported as working in 1884. Storage basins were built of masonry and lined with cement. These basins had a capacity of 78,000,000 gallons. The Moors introduced irrigation into Spain and the system which they established is retained in all its essential features. The first extensive irrigation works in the United States were constructed by the Mormons in Utah, in which state irrigation is an absolute necessity to successful agriculture.

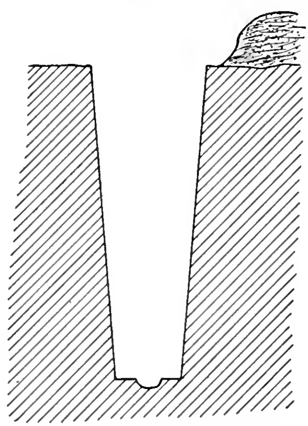


FIG. 55. Section of ditch, showing a groove at the bottom

258. *Present importance and distribution*—Extensive systems are now in use in India, Egypt, Italy, Germany, England, Scotland, some parts of South America, and in the United States, as well as in some other countries.

The amount of land under irrigation in some of the principal countries was reported by Wilson in 1893 to be as follows: —

India,	25,000,000	acres.
Egypt,	6,000,000	"
Italy,	3,700,000	"
Spain,	500,000	"
France,	400,000	"

According to the report of the eleventh census the number of acres under irrigation in the United States at the time it was taken was 3,600,000 acres. At the time of that census, canals and ditches had been constructed with capacity to provide water for a much larger area. The irrigated farm lands of the United States are for the most part west of the Mississippi river, in which portion of our country the rainfall is comparatively small and uncertain. Some of the largest irrigation works are in California. As an example may be mentioned the so-called Bear Ditch, which is 170 miles long and cost $2,500,000. This canal carries 3,888,000 cubic feet of water a day, sufficient to furnish some of our smaller cities such as Northampton, Burlington, or Bangor with water for an entire year. Bear Ditch irrigates about 293,000 acres. In India, where also the rainfall in many sections is insufficient to make farming without irrigation safe, many of the systems are of enormous capacity, canals being used for navigation as well as for irrigation. The Ganges canal is 900 miles long, 170 feet wide, and 10 feet deep and irrigates 1,500,000 acres. In Italy all the streams are controlled by government in the interests of irrigation, and in the case of the Humboldt river the entire volume of water has been diverted and used.

259. *Reasons for irrigation* — The large proportion of water found in growing plants, and the relatively enormous quantities needed to produce a pound of dry matter in a plant, have been pointed out (14, 19, 92). It has also been pointed out that during the growing season the rainfall is often insufficient, even in the Atlantic states, to furnish the amount of water needed for the best growth of our crops (92). The rainfall in the United States in any given latitude decreases with considerable regularity from the Atlantic seaboard westward to the Rocky Mountains, and farther west than

longitude 97 from Greenwich, the annual rainfall is seldom sufficiently great to produce maximum crops, while during several years in every decade unusual drouths cause enormous damage to crops. With a plentiful supply of water, plants have been grown even in sand and in coal ashes, while with an insufficient supply of water the best loam cannot support plant growth. The soil of a large proportion of the territory lying between the Mississippi and the Rocky Mountains is well stored with the elements of fertility, but without irrigation crops are small and uncertain. In the production of a bushel of potatoes it has been estimated that the plants will consume no less than 630 gallons of water, or about 16 barrels. If this amount is not available the crop suffers, and if it is irregularly supplied there is lessened yield. The first indication of the need of water afforded by the plant is wilting, but the plant does not wilt until it loses a large proportion of its moisture, at which time it is likely to have been considerably checked in its growth. The chief reason, then, for irrigating in most localities where the practice is extensive, is to furnish an adequate supply of water which shall be ready for use on demand. Under irrigation risk from untimely drouths is avoided, and the crop is assured so far as water is concerned. Irrigation greatly increases the value of farm lands, because the products are larger than without it, and more certain. In some localities west of the Mississippi, land, which without irrigation is almost valueless, readily sells for from $30 to $50 per acre when water is brought to it. The water used for irrigation, as implied in the definition of that word (256), may be the means of carrying large amounts of plant food to the soil. The water of rivers and streams is likely to prove the most valuable in this direction, although even spring and well water may contain elements of plant food in appreciable amounts. The water from the sewerage systems in our cities is of course far richer than any natural source of supply.

260. *Irrigation profitable in the North Atlantic states* — Irrigation cannot be looked upon as an absolute necessity for profitable agriculture in the New England and the Middle states, for these states are favored with fairly abundant and well distributed rainfall, but that irrigation in this section of the United States is often exceedingly profitable is abundantly demonstrated

by the experience of many practical men. This portion of the United States, though suffering less seriously than portions of the country farther west, is nevertheless subject to drouth, and crops often suffer severely. There is seldom a season with rainfall so abundant and so well distributed that crops of many kinds might not be increased by the judicious use of water in irrigation. It must constantly be kept in mind that the fertility carried to the field by the water, as well as the water itself, contributes to increased yield. Owing to the comparatively dense population of the north-eastern portion of the United States, a considerable proportion of the land used in the production of garden crops has a very high average value per acre; and, because of the density of the population, markets are good and the value of the possible crops from a given area is comparatively high. For these reasons also it may be profitable for the farmers and gardeners in this part of the United States to go to much greater expense to procure water than could safely be incurred by farmers in other sections of the United States. As a matter of fact, however, water which may be used for irrigation can be very readily and cheaply obtained in many localities. This section of the country has innumerable lakes and ponds, streams and rivers, and springs, from which water can in many cases be readily taken, and the broken and rolling nature of the country offers great advantages in the distribution of water. It must be apparent, therefore, that while agriculture without irrigation is possible and may be profitable, there is perhaps no section of our country where irrigation promises greater profit.

261. *The fertilizing value of irrigation waters* — That the water used for irrigation contributes to the fertility of the fields in which it is used has been pointed out (256, 259). How large the supply of plant food from this source may be will be made more clear by a statement of the results obtained by calculations based on the reported analyses of the water of a few of our rivers. The application of water from the Delaware river to the depth of 24 inches, which is an amount no greater than is frequently used in irrigation, would supply to the acre of land no less than 741 pounds of solids containing very considerable amounts of nitrogen, phosphoric acid, and potash, as well as lime, magnesia, and other minerals which enter

plants. The application of the same amount of water, having the same composition as the average of twelve rivers of New Jersey, would supply to an acre of land no less than 80 pounds of nitrogen in the form of ammonia and 770 pounds of nitrates. All of these streams are regarded as comparatively pure and the water is in some cases used as the source of domestic supply for cities. If the water of such rivers carries such enormous amounts of plant food it must be apparent that river water in general will furnish sufficient plant food to be of great value. Further evidence of the great fertilizer value of water used in irrigation is afforded by the water meadows of England, some of which have been producing enormous crops of grass yearly for perhaps 300 or even 500 years and all this time without the application of manure or fertilizer of any kind. The amount of water applied to these meadows is very large. Their value is naturally very high. Water can be applied to them more cheaply than manure, even if the latter could be had for the hauling. Crops are absolutely certain and by feeding the product of these meadows and carefully saving the manure, the unirrigated portion of the farms having water meadows is maintained in a very high state of fertility.

262. *Kinds of water available for irrigation* — Among the different sources of water which may be available for irrigation in different parts of the Northeastern states are rivers and streams, ponds and lakes, springs, wells, and sewage. As a general rule that water is best for irrigation which contains a large amount of suspended and dissolved materials, provided these are not of a kind to be injurious to plant life. It is further important that water which is to be used for irrigation should have a high temperature, for the application in large quantities of very cold water will seriously check the growth of most crops for a time.

(*a*) *Rivers and streams* — Facts have been stated which make it evident that rivers and streams often carry large amounts of plant food. Those whose waters are turbid, carrying considerable quantities of fine earth, are among the best for use in irrigation. Where these turbid waters can be so spread over the surface of fields as to come to partial rest, the fine earth settles and serves to greatly enrich the soil. Such water is

especially useful when applied to soils of a sandy or gravelly character, for the fine silt deposited from the water will greatly improve the physical characteristics of such soils. The water from rivers and streams may in many cases have a sufficiently high temperature for immediate application, but in some cases it is so cold that it is greatly improved if it can be first led into a shallow reservoir where it may be warmed by the sun before it is finally distributed in the field. This point is particularly important in the case of garden and field crops. If the water is to be used for grass it may safely be taken directly from the rivers and streams.

(*b*) *Ponds and lakes* — The water from ponds and lakes is likely to be of the same general character as that of the rivers and streams in the same section of country. It will, however, in many cases be somewhat richer in plant food, owing to the evaporation of a portion of the water originally brought into the pond or lake. The temperature of course varies widely with the depth and with the source from which the pond or lake is fed, but as a rule it will be sufficiently high so that the water is fit for immediate use.

(*c*) *Springs* — The water from springs, though varying widely, is in many cases comparatively pure and cold. In most instances it should be led into a shallow reservoir that it may be warmed by the sun before being used.

(*d*) *Wells* — Water in surface wells is of the same general character with spring water, comparatively pure and cold. It is by no means equal to river water for use in irrigation but there are many instances of its profitable use. It must first be pumped into a tank, or better into a shallow reservoir, that its temperature may be raised before it is applied. Artesian wells, which are so important in some parts of the West, are not of much importance in the North Atlantic states. Water from such artesian wells as have been made in this section is generally highly pure and cold.

(*e*) *Sewage* — Sewage must be regarded as the best water for irrigation. It contains a larger proportion of plant food than any of the other kinds considered, and its temperature is higher than that of other kinds of

water which can be obtained. The proportion of plant food in sewage varies widely, depending to a great extent upon the system of sewerage employed in the city or town from which it comes. Sewage, the popular impression to the contrary notwithstanding, is not sufficiently rich in plant food to make it possible for farmers and gardeners who might use it to pay any very considerable sums for this material. True, the aggregate value of the sewage from our large cities is enormous. Thus, for example, it is estimated that at the same price per pound for the potash, phosphoric acid, and nitrogen, at which these materials can be purchased in fertilizers, the sewage of the city of Boston would be worth $2,000,000 ; that of the city of New York, $9,000,000 ; but the dilution is so great that it does not pay to use sewage except under the most favorable circumstances. It has been calculated that a ton of London sewage contains not more than 5 ounces of the elements of plant food. The question as to the disposal of sewage is in this country still almost exclusively a sanitary question. Our sewers, it is true, carry into rivers, lakes, and the sea, enormous quantities of plant food ; but if, as in many cases is true, it costs more than one hundred cents to recover one dollar's worth of this plant food, it would be poor economy to undertake its recovery, provided the sewage can be safely disposed of in some other way. There are some instances of successful sewage irrigation in this country, and a very considerable number in England and on the continent of Europe, but in very few of these instances is such irrigation attended with results which can fairly be considered profitable. The impression is doubtless quite general that sewage irrigation is attended by disagreeable features, but when it is rightly carried on this is not the case ; and, moreover, there appears to be no method whereby sewage can be so efficiently purified as by its use in suitable amounts in the irrigation of soils of an open, porous character.

263. *Water from cities or towns* — Cities and towns, or private companies supplying cities and towns, are sometimes ready to sell water for irrigation at rates which allow its profitable use. This they can easily do whenever their supply is in excess of the requirements of the communities supplied, for whether their water comes through their pipes under pressure

of a natural head, or whether they must pump, their works are generally on a large scale and the actual cost of the water which they deliver low. There is no doubt that, with modern machinery, water is often pumped to a considerable elevation at an actual cost of less than five cents per 1,000 gallons. Such water is usually metered to those using it for irrigation, and prices as low as twenty cents per 1,000 gallons are not uncommon. It is the market gardeners and small fruit growers near cities and large towns, chiefly, who find it profitable to avail themselves of this source of supply. Such water is taken as a rule from a natural stream, river, pond, or lake, and its qualities are similar to those of the purer natural bodies of water of this class. There are many instances in Massachusetts of the successful use of city or town water in irrigation.

264. *Irrigation terms and units* — The term miner's inch, much employed in connection with irrigation in the West, designates the quantity of water which will flow through an opening one inch square under a head of 6 inches from the upper side of the opening. The miner's inch equals about 12 gallons per minute, and 50 miner's inches furnish about 1 cubic foot of water per second. The acre-inch is an expression indicating sufficient water to cover one acre of land 1 inch deep, or 6,272,640 cubic inches, and an acre-foot designates sufficient water to cover an acre 1 foot deep, or 43,560 cubic feet. A gallon equals 231 cubic inches. An acre-inch is equivalent to a little more than 27,000 gallons. A cubic foot is equal to about 7½ gallons. A stream of water, the cross section of which is 1 square inch, flowing at the rate of 4 miles per hour, will furnish 6,082,560 cubic inches of water in 24 hours, which is therefore sufficient to furnish almost an acre-inch, or, in other words, to cover one acre of land almost 1 inch deep.

265. *Crops for which irrigation is desirable* — In humid climates market gardens are undoubtedly more often irrigated at large profit than any other class of farm lands. Among the reasons why this is so are the following: —

1st. The land employed in market gardening usually has a very high value and must therefore be made very productive in order that any profit may be obtained in its cultivation.

2d. The style of cultivation adopted in market gardening is very intensive. Heavy applications of manures and fertilizers are made and laborious methods of culture adopted. The cost per acre is therefore heavy and there must be large returns, or operations will be carried on at a loss. Injury to crops from drouth under these conditions is especially disastrous. Ordinary farm crops in the Northeastern states may not be worth more than from $25 to $50 per acre, but the crops of the market garden are often worth from $250 to $300 per acre. It is perfectly evident from this statement of facts that the market gardener can afford to pay much more for water than the ordinary farmer. A decrease in his crops, amounting to a loss of half an average product, as a result of drouth is not uncommon. The cost of water for irrigation will in many cases be trifling in comparison with the money loss resulting from such a decrease in crops.

Small fruits also are greatly benefited by irrigation. Among these the most important are the strawberry, raspberry, and the blackberry. Especially does irrigation benefit the first of these. The late Marshall P. Wilder, being asked what were the requisites for successful culture of strawberries, is said to have replied: "First, plenty of water; second, plenty of water; third, plenty of water." A sufficient water supply enables the vines to carry out their fruit and to produce berries of good size throughout the entire season. The crop possibilities under judicious irrigation are enormous. The writer, on a small piece of land, once had a crop at the rate of 21,000 quarts to the acre.

The cranberry is a crop for which irrigation is absolutely essential. True, the culture of this crop is sometimes attempted where a sufficient supply of water for flooding is not available, but the degree of success possible under such conditions is very small. The crop is greatly benefited by flooding in winter as a protection from injury from cold. Flooding both in spring and in autumn to avoid frosts is a great safeguard against loss; while, further, for protection against certain insects, flooding is the best method which is known.

Grass. The amount of water required by the grasses is very large, hence irrigation of meadows is advisable wherever it can be given without

too great expense. Grass, filling the soil entirely with a mass of fine feeding roots, utilizes the elements of fertility in water employed for irrigation more perfectly than any other crop. Covering the ground fully, grass protects the soil from washing; and occupying the field permanently, the ditches and channels used for distributing the water are more permanent than in the case of fields occupied by hoed crops. The cost of distributing water for the irrigation of grass lands is less than in the case of most other crops. Among the grasses which are best suited to irrigation are blue joint, Italian rye grass, perennial rye grass, fowl meadow, rough-stalked meadow, tall oat grass, and orchard grass. Timothy and clovers do not thrive well under heavy irrigation. On the ordinary farm, if the water available for irrigation is sufficient only for a portion of the improved areas, then it will generally be best to use that water on the grass lands rather than for hoed crops.

Corn, on warm and porous soil which is perfectly drained, thrives under very abundant irrigation and in some localities it has been found especially well suited for culture under sewage irrigation. Enormous crops of ensilage corn are grown at many of the State institutions in Massachusetts under sewage irrigation, while the city of Brockton in Massachusetts has had great success in the production of sweet corn on its filter beds under very heavy applications of sewage.

The Japanese barnyard millet is also adapted to culture under liberal irrigation with sewage.

Orchards. The tree fruits grown in humid climates send their roots to such depth that irrigation is perhaps less necessary than for many other crops, yet it is well known that the size of the fruit, and therefore the yield and the price at which it can be sold, is affected in very marked degree by the water supply. Protracted drouth frequently causes our apples, peaches, and pears to be small. Judicious application of water will prevent this injury to these crops.

266. *Land best suited for irrigation* — That land can be most profitably irrigated, of course, which is nearest the source of supply and which lies at such a level that water will flow to it by gravity. The surface should not

be, on the one hand so flat as to render distribution difficult, nor on the other hand so steep that washing is likely to occur to a serious extent. Steep slopes may indeed be successfully irrigated if kept in grass, but they are not so easily irrigated when in hoed crops. The lighter soils are more benefited by irrigation than the heavier. Their capacity to hold water is small (74), they have little capillary power (94). Crops on them accordingly suffer quickly in dry weather. Such soils are especially adapted for sewage irrigation. Heavy soils can be successfully irrigated, provided they are well drained or can be drained. Whether the soil be heavy or light, the water-table should be low in all cases where large quantities of water are to be employed. Especially is this essential in the case of sewage irrigation. The cities and towns from which sewage is taken generally stand upon comparatively low land. It is accordingly expensive to take the sewage to the land, as pumping is, in the majority of instances, a necessity. In order to reduce the cost of distribution as much as possible, the tendency is to use enormous amounts of sewage upon comparatively small areas. This would render the soil unproductive unless it be of a very open and porous character, thoroughly drained, and the water-table a considerable number of feet below the surface. A further reason why the lighter soils are best adapted for irrigation is because they are less liable to injury to tilth by abundant use of water. The heavier soils, if used for hoed crops, must be irrigated with care lest the surface soil become puddled. Such soils, if water is to be used abundantly, are generally most profitably kept in grass.

XLI — METHODS OF OBTAINING WATER FOR IRRIGATION.

267. *Leading out water from streams* — This is the simplest and one of the commonest methods of obtaining water for irrigation. It is only necessary to cut a ditch or canal of suitable size, starting at a point on the stream at the head of the tract to be irrigated. This ditch is given a very slight grade, and, leaving the stream, it is made to follow along the upper edge of the valley lying between it and the stream. Where the fall in the valley is considerable, very wide areas may sometimes be irrigated from such a ditch. In some instances the level of the water in the stream from which it is to be

taken may easily be somewhat raised by the construction of a dam at the point where the ditch leads out. This will increase the area which may be irrigated.

268. *Storing storm water* — Dams can sometimes be constructed at the mouth of narrow ravines or valleys which will make it possible to retain and hold for use in irrigation large quantities of storm water. In this way such water may be made useful in irrigation instead of, as is so often the case at present, pouring into the streams and causing floods which leave destruction in their wake. The farmer cannot be advised, however, to attempt the construction of a dam of considerable size without the assistance of an engineer.

269. *Under-flow from higher lands, springs, under-drains, etc.* In the hilly districts of the Northeastern states, as has been pointed out under drainage (194), there are many localities where there are large amounts of ooze or spring water which might easily be collected and stored in reservoirs. In some cases the water which flows through under-drains may similarly be collected and made to contribute to the productiveness of other farm lands.

270. *Water wheels and rams for raising water* — The water in streams not infrequently is at so low a level that it must be raised by some means before it can be used in irrigation. Among the Japanese and Chinese a water wheel worked by man power is much employed, but with our more expensive labor this is impracticable. In case a stream from which water is to be taken is large, it can be made to lift a portion of its water to a moderate height by means of an ordinary under-shot wheel with buckets on one or both sides. In a bulletin on irrigation in humid climates, King mentions having seen such a wheel 16 feet in diameter, making four revolutions per minute, and raising more than 300 gallons of water per minute to the height of 12 feet. The hydraulic ram is generally too well known to need description. Under suitable conditions it may be a very effective means of raising water.

271. *Raising water by wind power* — Windmills furnish a satisfactory means of pumping water in some localities. Especially is this true near the

seashore and in the prairie states. Such mills are less likely to prove satisfactory in hilly and broken districts. King has made accurate observations upon the use of windmills for raising water for irrigation and he gives the following table: —

Number of acres a first-class windmill will irrigate two and four inches deep every ten days when working eight hours per day, and lifting the water ten, fifteen, and twenty-five feet respectively.

Diameter of Windmill Wheel.	Lift of 10 Feet.		Lift of 15 Feet.		Lift of 25 Feet.	
	2 Inch.	4 Inch.	2 Inch.	4 Inch.	2 Inch.	4 Inch.
Feet.	Acres.	Acres.	Acres.	Acres.	Acres.	Acres.
8.5	1.35	0.67	0.9	0.45	0.55	0.27
10	4.27	2.13	2.85	1.42	1.70	0.85
12	7.66	3.83	5.11	2.55	3.00	1.50
14	9.87	4.93	6.58	3.29	3.99	1.99
16	13.79	6.89	9.19	4.59	5.71	2.85
18	22.09	11.04	14.14	7.07	8.64	4.32
20	27.36	13.68	18.25	9.12	11.04	5.52
25	47.06	23.53	31.38	15.69	18.77	9.38
30	95.46	47.73	64.42	32.21	38.08	19.04

Where windmills are depended upon as a source of power it is desirable to have considerable storage capacity, in order that there may be a sufficient supply of water to last through periods of calm.

272. *Lifting water with engines* — The modern heat or steam engine is a fairly efficient machine, doing a large amount of work in proportion to the amount of fuel consumed. A statement has been made concerning the cost of pumping water in case of the large plants of water companies (263). Some experiments have been carried out at the Wisconsin experiment station to determine the cost of pumping with an ordinary farm engine. It was found that with a rated 8-horse-power engine, water could be drawn through 110 feet of 6-inch pipe and raised 20 feet at the rate of 22⅛ acre-inches a day with one ton of coal. At $4.00 per ton the fuel-cost for 4 acre-inches lifted 26 feet was $0.72, or for 6 such irrigations, $4.32; or upon the basis of the 20-foot lift the cost for 6 irrigations was $3.03. The centrifugal pump was used in these experiments. Such pumps should always be

selected when the height to which the water is to be raised does not exceed about 25 feet. They are simple in construction, not liable to get out of order, durable and cheap. If the lift exceeds 25 feet a plunger pump should be used, in which case both the suction and discharge pipes should have a diameter about equal to that of the plunger. If this is not the case the pump does not work to the best advantage.

XLII—METHODS OF APPLICATION.

273. *Distribution to different parts of the field*— Whatever the manner in which water is finally directly applied to the field to be irrigated, there are several different systems employed for taking it from the source of supply to the field and there distributing it to different parts of the field. Among these, simple open ditches, troughs, and pipes are the most common. The open ditch has the advantage of being cheap, but the very great disadvantage that the water is subject to loss both by seepage into the soil and by evaporation. Moreover, when water flows through open channels the line of its progress must be a continually descending one. To secure a satisfactory grade is sometimes difficult, and when water is taken from an elevated reservoir or tank the loss of head due to leading it through graded ditches is often a serious matter, in many cases greatly reducing the area which can be watered.

The trough has the advantage over the ditch that loss by seepage is prevented. Troughs, however, are perishable, and they allow evaporation, and must follow a steadily descending line, thus involving the loss of head. It will be seen, therefore, that troughs (far more expensive than open ditches) have nearly all their disadvantages. The loss of head, it is true, can be in a measure prevented by supporting the trough on benches or otherwise above the surface of the ground, where so doing is an advantage.

Everything considered, the iron water pipe appears to be, for the Northeastern states, at least, the most satisfactory means of conveying water from the place of storage to the field, and of distributing to different parts of the field. In some cases these pipes are permanently laid under ground, but in the majority of instances they are placed on the surface, and are taken

up whenever plowing or any other operation in the field renders it desirable. If laid under ground, such pipes must either be so graded that they can be emptied of water or put below the reach of frost. The first of these methods is usually preferable, on account of the lesser cost. When laid on the surface, such pipes must of course be emptied during the winter. In whatever way pipes are laid, suitable gates and connections must be put in to facilitate taking water to the different parts of the field as required, and for drawing it wherever it is desirable.

274. *The various methods of application* — Water may be applied for the different crops in many different ways, the more important among which are sprinkling, flooding, percolation, and sub-irrigation.

(*a*) *Sprinkling* — Wherever water is extensively applied by sprinkling, the work is commonly done by means of hose with suitable distributing nozzle or rose at the sprinkling end. It is not convenient to employ hose of more than about ¾ inch diameter, and lengths of 100 feet are as great as can be easily handled without injury to the growing crops. The application of water in this way is usually limited to comparatively small areas such as market gardens or lawns. In some instances the different forms of lawn sprinklers may be used with satisfaction, although the expense and trouble of frequently moving them will commonly preclude their extensive use.

(*b*) *Flooding* — Under this system the water is spread over the ground to be irrigated in as even a sheet as possible. There are several different systems by which this result is obtained: First, by flooding directly from the ditch; second, by sloping the field into benches divided by means of low sod banks; and, third, by the check system, in which the field is laid off into checks surrounded by low sod banks. Under either of these systems the farmer holds the water at one level as long as he desires, then allows it to flow to the next lower, and thus in turn he floods the different sections into which the field is divided. This system is especially adapted for the irrigation of grass lands.

(*c*) *Percolation* — Under this system the water is allowed to flow slowly through small furrows out of which it soaks into the adjoining soil. The

distance between these furrows must vary with the nature of the soil and with the crop. They must be closer together in the more open and porous soils than in those which contain considerable silt or clay. It is essential that these furrows have only slight grades. If the grade be steep it is difficult to distribute the water evenly and there is danger of washing. This system is fairly well adapted to the irrigation of vineyards and orchard trees, as well as for that of the various field and garden crops grown in rows, such as corn, potatoes, grain in drills, etc. It is also well suited for the irrigation of strawberries and other small fruits where the fields are fairly level. In all these cases the furrows are opened between the rows at such distances apart as experience shows to be necessary to secure a fairly even distribution of moisture to all parts of the field. Distribution of water under this system requires considerable attention.

(*d*) *Sub-irrigation* — Sub-irrigation is generally carried out by laying drain tiles under ground, the water flowing into the tiles finding its way out at the joints. These tiles must usually be placed sufficiently deep to be safe from disturbance by plow or other implement of culture, and the interval between the different lines of tiles must be varied with the soil. To secure even watering they must generally be rather close together, say some 12 to 15 feet. Some of the advantages of this system are that as no water is applied to the surface the soil is not puddled and does not break and crack. The water being applied under ground there is less loss by evaporation, and the soil is therefore cooled less than by any system of surface irrigation. Less water is required than in surface application, but the system is a costly one, as the expense of purchase and laying the tiles will be heavy. While, therefore, sub-irrigation in hothouses is considerably used, it is not often employed in fields or gardens. When, however, the conditions are such that each line of tiles can be led out directly from an open ditch of such a grade that, by simply filling the ditch with water, it will flow into every line to its full length, the system has great advantages. There is no other whereby the labor-cost of irrigation can be kept so low, and when the soil is of such a character that water moves through it with a fair degree of rapidity, so that the distances between the lines may be considerable, it may

pay to irrigate upon this plan. The writer has seen in connection with a market garden near Boston a very successful instance of sub-irrigation. In this case box drains of the ordinary construction are used in place of tiles. The field is comparatively flat ; the boxes serve as drains during such seasons of the year as the natural water supply is excessive, and whenever the crop needs watering this is accomplished by simply filling the ditches into which the boxes lead. It is believed that the system would have been more satisfactory in the end had tiles instead of box drains been used.

275. *The amount of water needed in irrigation* — The amount of water which can be profitably used in irrigation will vary with the character of the soil and subsoil, the climate, and the crop. The lighter the soil and the more open the subsoil, the more water must be used. In the humid climate of the Northeastern states the amount of water required in irrigation is less than in the arid West, and as the amount of rainfall varies widely in different seasons, no very definite statements as to the quantity of water which should be employed are possible. Wilson states that not less than 50,000 gallons per acre will be at all satisfactory. In some experiments in Wisconsin in irrigating corn 2 acre-feet of water were applied in six irrigations of 4 acre-inches each, and the results were considered very satisfactory. Among the different crops grass will thrive under more abundant irrigation than most of those which are cultivated in the Northeastern states. In sewage irrigation perfectly enormous amounts of water are sometimes employed. It is estimated that the daily consumption of water in most of our American cities will amount to at least 75 gallons per individual, and few authorities on sewage irrigation advise the use of a less amount of sewage than that from 100 individuals, while as great an amount as that from 300 individuals is sometimes applied with fairly satisfactory results. On the basis of 100 individuals to the acre the daily amount of sewage would amount to at least 7,500 gallons. For the growing season of, let us say, 150 days, the total amount of water applied to the acre would amount to 1,125,000 gallons. This is equal to about 42 acre-inches, or a layer of water 3½ feet in depth applied during the period under consideration. It will be understood, of course, that it is not the rule to apply water, even in

sewage irrigation, daily. It is far better to apply it in moderately large quantities at intervals of several days. In conclusion it may be said that during the period of most rapid growth of many of our garden and field crops an application of about 2 acre-inches of water once in from 7 to 14 days is not usually more than can be used with advantage.

276. *The cost of irrigation* — The cost of irrigation depends, of course, very largely upon conditions. The cost of the water fluctuates widely. If it be purchased from a town or private water company at 20 cents per 1000 gallons, then each acre-inch (27,000 gallons) would cost $5.40, and the 4 or 5 waterings which the crop may require may easily, therefore, cost from $20 to $40, according to the amount used. Wilson states that a plant consisting of a reservoir 65 feet in diameter and 8 feet deep and a 16-foot windmill and pump cost about $450. He further states that this plant would pump about 2,000,250 gallons of water in five months to an altitude of 50 feet. This would be sufficient to cover 15 acres 6 inches deep. The celebrated nurseryman, Mr. Vick of Rochester, New York, is stated to have a plant of about this capacity and it has been able to supply sufficient water for the irrigation of 15 acres of nurseries and to supply in addition several greenhouses, a dwelling-house, and a stable. With such a plant the cost of irrigation must clearly depend upon the amount of repairs and attention required, and these figures are so variable that a definite statement of cost is impo sible. It should, however, be very low.

277. *When to irrigate* — As a rule it is preferable to irrigate during late afternoon, early evening, or on a cloudy day. If water be applied on the surface during a bright, sunny day the evaporation is considerable. Water is lost thereby and, even more serious, the soil is cooled. In the case of grass and orchards it is less necessary to apply water at such times as above indicated, since these crops shade the ground and are less injured by the reduction in the temperature of the soil incident to application of water during sunshine. The frequency of irrigation depends upon the soil and the crop. The rule should be to irrigate before the soil gets dry. This is usually once in from about 8 to 14 days. If possible the water when applied should have about the same temperature as the soil. Water thoroughly

before sowing or transplanting, and, as a rule, somewhat more moderately afterwards. It is best, however, when water is applied to use sufficient to moisten the soil thoroughly to a considerable depth. The frequent application of small quantities of water at the surface, especially by sprinkling, is sometimes more harmful than beneficial.

278. *Management of irrigated land* — This subject requires treatment under two heads : 1st, Grass lands ; 2d, Cultivated lands.

(*a*) *Grass lands* — Where grass lands are irrigated measures must be taken to make and to keep the surface smooth. Occasional rolling will be required. Irrigation of grass lands should stop sufficiently long before the crop is to be cut to allow the soil to become firm so that it may not be cut up in the operations of harvesting. Irrigated lands are sometimes pastured but the results will be unsatisfactory unless the following precautions are observed : 1st. Allow sufficient interval between the last irrigation and the turning in of the animals so that the soil may become moderately dry and firm. 2d. If the growth is rank it will be found a great advantage to use portable fence, confining the animals successively to small portions of the field. If this is not done they will trample down and destroy large amounts of feed. The heavy animals, such as cows and horses, are on the whole not well adapted for the pasturage of irrigated grass lands. They damage the surface too seriously. Sheep are much better fitted for pasturing this kind of land, but with these animals foot-rot is likely to occur if they are turned in while the soil is still wet. On the whole it is believed that the crop of irrigated grass lands should be cut rather than pastured.

(*b*) *Hoed crops* — In the management of hoed crops which are irrigated the object should be to cultivate at such times as to keep the soil in good mechanical condition, and to conserve the water applied to as great a degree as possible (97). As soon as the soil can be worked after irrigation the surface should be mellowed. This tends to prevent crusting or cracking and greatly lessens the loss of water by evaporation. The interval between irrigation and beginning of cultural operations must of necessity vary widely with the soil. No definite time, therefore, can be stated. Each field is a special problem in itself and must be carefully watched to determine the proper time for cultivation.

279. *Loss of water from ditches and reservoirs* — A portion of the water taken into ditches or stored in reservoirs is inevitably lost. The losses are of two kinds: first, seepage, *i. e.*, soaking into the soil, and evaporation. Loss by evaporation depends upon the temperature, the humidity of the air, and the wind. In the dry air of Colorado it amounts to as much as 60 inches yearly. Even near the seaboard of Massachusetts the actual evaporation sometimes reaches 50 inches. This loss can never be entirely prevented, but wind-breaks so placed as to cut off the more drying winds may lessen it. Evaporation is greater from a shallow than from a deep reservoir, for in the latter the temperature of the water is lower. The amount of water lost by seepage, whether in reservoirs or in ditches, varies widely with the soil. In reservoirs special steps to prevent it may be taken, such as cementing the bottom or putting in a layer of puddled clay, and if the soil where the reservoir is placed is of an open structure such steps must be regarded as absolutely necessary. In the case of soils through which water is carried from the point of origin to the point of distribution, such steps as will fully prevent loss by seepage are hardly practicable. When the ditch is made in porous soil a loss of one-third or more of the total amount of water is not uncommon. If the water taken into the ditch is naturally turbid and the grade is slight, the fine suspended earth tends to settle on the bottom and in course of time seepage is reduced. In some cases it is practicable to mix finely divided clay with the water where it is taken into the ditch. Having done this, if the flow of the water in the ditch can be checked by putting in temporary stops, one section after another can be improved by the deposit of a portion of the clay in the bed of the ditch. If the clay is rich in lime it forms a very impervious coating. Before undertaking the construction of ditches for carrying water for irrigation, the soil over which the ditch must pass should be carefully examined. If it be very loose the system may be altogether impracticable, since water may soak into the soil to such an extent that little if any will reach the point where it is to be used. The writer has read of an instance in early Japanese history where, after enormous expenditure of labor and money in the construction of a large canal the whole

work was found to be useless, as the open soil swallowed up all the water which could be turned into the canal.

280. *Objections to irrigation* — The first cost of any irrigation system is considerable and this is perhaps the chief obstacle to its more extensive adoption in the New England states. The labor of applying the water is considerable in the case of many crops, and this also serves to deter many would-be irrigators. Moreover, in the humid climate of the North Atlantic states the amount and the time of rainfall is most uncertain. Irrigation may be almost immediately followed by rain, thus possibly making the land too wet, or, at least, causing unnecessary expense. The danger of making the soil too wet is but little if it be of the lighter and sandy character which has been stated to be best adapted to irrigation. Still further, all systems of irrigation break up the surface of the land to a greater or less extent and thus impede the use of agricultural machinery. In spite of all these points, however, the yield of many of our crops can be so enormously increased by judicious irrigation that its adoption under favorable conditions may be strongly urged.